No. 3

Proceedings

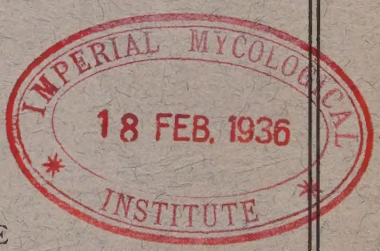
of

The Canadian Phytopathological Society

Third Session

July 25th to 28th, 1933

(REGINA, SASK.)



EDITORIAL COMMITTEE

H. T. GÜSSOW

J. G. COULSON J. H. CRAIGIE

The papers that appear here have been reprinted from the Proceedings of the World's Grain Exhibition and Conference, Regina, Vol. 2, without change of pagination.

OTTAWA

Published for The Canadian Phytopathological Society by the Canadian Society of Technical Agriculturists, Ottawa, Canada.

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THE CANADIAN PHYTOPATHOLOGICAL SOCIETY

LIST OF OFFICERS AND COUNCIL 1932-33

President

W. P. FRASER, University of Saskatchewan, Saskatoon, Sask.

Vice-President

D. L. BAILEY, University of Toronto, Toronto, Ontario.

Secretary-Treasurer

T. G. MAJOR, Central Experimental Farm, Ottawa, Ontario.

Councillors

G. H. BERKELEY, Dominion Laboratory of Plant Pathology, St. Catharines, Ont.
H. T. GÜSSOW, Central Experimental Farm, Ottawa, Ontario.

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BUSINESS SESSION.

The business session was held July 27. The President, Prof. W. P. Fraser, called the session to order at 9.45 a.m. The Chairman explained that when it had been decided to postpone the 1933 meeting, Council determined to suspend Article V of the Constitution and leave the election of officers until 1933. In this way the officers elected in 1931 were still carrying on their duties. This explanation was supported by reading extracts from the minutes.

The minutes were read by the Assistant Secretary-Treasurer, Mr. N. A. MacRae. It was moved by T. C. Vanterpool, seconded by I. L. Conners, that the minutes be accepted as read. Carried.

The Chairman appointed T. C. Vanterpool and W. F. Hanna to be Chairmen of the Publicity and Resolutions Committees respectively.

Before Mr. MacRae read the Secretary-Treasurer's report, he took the opportunity of expressing Mr. Major's regrets for his inability to be present. He also assured the Society that it was with considerable hesitancy that the latter had decided to relinquish his post as Secretary-Treasurer. No member of the Council was more conscientious or more interested in the welfare of the Society than Mr. Major. Mr. MacRae also paid particular tribute to the Chairman of the Local Committee, Dr. P. M. Simmonds, who was responsible for the present excellent arrangements for holding the meeting. The adoption of the Secretary-Treasurer's report and Financial Statement was moved by A. W. Henry and seconded by T. C. Vanterpool. Carried.

It was moved by G. B. Sanford, seconded by P. M. Simmonds and carried, that the incoming Secretary-Treasurer make the necessary arrangements to have the books audited at an early date. The report of the Custodian of Records was then read and adopted.

At the second Annual Meeting, a motion was carried that a mail ballot be taken on the proposed amendment to Article 6. As a result of the ballot the amendment was carried unanimously.

Article 6, section (d) as amended reads as follows:—

(*d*) One ballot shall be mailed to each member. Each member in good standing (*e*) shall be entitled to indicate his preference for the candidates for each office by marking a first and second choice in each case. The ballots shall be counted by a committee of three scrutineers appointed by the President, and to whom they shall report. The "first choice" votes for each office shall be counted first, and, if one of the candidates shall have obtained a greater number of such votes than the combined totals of the other two, that candidate shall be declared elected. In the event of no candidate for a given office thus receiving a majority vote on the first count, the "second choice" votes on the ballots of the candidate receiving the fewest number of "first choice" votes shall be added to the "first choice" votes of the remaining two candidates respectively. The candidate thereby receiving the greater number of "first choice" and "second choice" votes on the second count shall be declared elected. In the event of a tie on either the first or second counts the President shall cast the deciding vote.

On behalf of the Council, J. H. Craigie nominated M. Etienne Foex, Versailles, France, to honorary membership. M. Foex was unanimously elected.

As no candidate had made application for membership in the Society there was no election of regular members.

It was moved by A. W. Henry, seconded by J. H. Craigie, and carried, that the Secretary be instructed to notify members under suspension for non-payment of their fees that their names will be dropped unless these fees are paid within one month after the notice is sent.

I. L. Conners nominated C. G. Riley to position of Custodian of Records and Assistant Secretary-Treasurer. It was moved by G. B. Sanford, seconded by P. M. Simmonds, and carried, that nominations close. Mr. Riley was unanimously elected.

J. H. Craigie as a member of the Editorial Committee stated that his duties had been merely nominal. On the other hand, Dr. H. T. Güssow had taken the full responsibility in the negotiations for the publication of the 1931 Proceedings. It was moved by G. B. Sanford, seconded by R. C. Russell, and carried, that the Editorial Committee be commended for the excellence of the "Proceedings." The hope was also expressed that the same high standard of excellence might be maintained in future.

I. L. Conners, Chairman of the Common Names Committee, reported informally on the progress made by the Committee since the last meeting. A determined effort will be made to present a final report at the next annual meeting. The work of the Chairman was favourably commented upon.

The slate of new officers was then read. A letter from Dr. D. L. Bailey, expressing his regret for his inability to be present, was read by the Secretary. It was moved by J. H. Craigie and seconded by P. M. Simmonds that the Resolutions Committee prepare a suitable reply. Carried.

The Council pointed out that Dr. Güssow had promised at the last meeting to present a paper on photographs and illustrations at the present session. It was moved by T. C. Vanterpool, seconded by J. H. Craigie, and carried, that the Secretary be instructed to write Dr. Güssow requesting him to present this paper at the next meeting.

It was moved by T. C. Vanterpool, seconded by N. A. MacRae, and carried, that a secret ballot be adopted, and that the Secretary make the necessary arrangements. A ballot similar to that used by the C. S. T. A. was favoured.

As the bank account of the Society was in the name of the retiring Secretary-Treasurer, it was moved by N. A. MacRae, seconded by J. H. Craigie, and carried, that the account be transferred to the name of the Society, and that the bank be authorized by the President to permit the incoming Secretary-Treasurer or the Assistant Secretary-Treasurer to transact business for the Society.

J. H. Craigie stated he had received a request from Dr. H. M. Quanjer, soliciting a contribution to the Eriksson Prize Fund from the Canadian Phytopathological Society. If sufficient funds are made available, the next award will probably be made for work in the field of virus diseases. It was moved by I. L. Conners, seconded by N. A. MacRae, and carried, that although the request of Dr. Quanjer for a contribution to the Eriksson Prize Fund had been given sympathetic consideration, the Society was not prepared to make any financial contribution at the present time.

It was moved by N. A. MacRae, seconded by J. H. Craigie, and carried, that the bill tendered by Mr. H. L. Trueman, General Secretary of Canadian Society of Technical Agriculturalists, for printing of the 1931 Proceedings of Canadian Phytopathological Society, amounting to $265.00, be received and paid.

Mr. Trueman reported briefly on the aims of the C. T. S. A. in preparing project reports of the Agricultural Research work under way in Canada. In the field of Phytopathology, Prof. J. G. Coulson had assembled the University projects, while Dr. H. T. Güssow had similarly compiled the projects under way in the Department of Agriculture. These projects had not been mimeographed, but they were available for consultation in his office. It was moved by A. W. Henry,

seconded by N. A. MacRae, and carried, that a copy of the projects be deposited in the hands of the Custodian of Records, and that the Council be requested to determine whether mimeographed copies of the Phytopathological projects should be made available to the members of the Society.

It was moved by W. P. Fraser, seconded by J. H. Craigie, and carried, that mimeographed copies of the minutes of this meeting, and of the Secretary-Treasurer's report and Financial Statement be sent to all members of the Society.

The Secretary read a letter from Dr. D. L. Bailey, in which he, with Prof. R. B. Thomson and the staff of the Botany Department of the University of Toronto, invited the Canadian Phytopathological Society, to hold its next annual meeting in conjunction with that of the Botanical Society of America, which is tentatively set for next summer at Toronto. It was moved by J. H. Craigie, seconded by A. W. Henry, and carried, that the invitation be gratefully acknowledged and that the final decision as to place and date of meeting be left to Council.

It was agreed that the Resolutions Committee should report at the beginning of the Friday afternoon session.

It was moved by G. B. Sanford, seconded by J. H. Craigie and carried, that the thanks of the Society be expressed to the Council and to Dr. P. M. Simmonds of the local committee for arranging the excellent programme and details of the present meeting.

It was moved by J. H. Craigie, seconded by G. E. Woolliams, and carried, that Prof. J. G. Coulson continue to be the representative of the Society to the Canadian Society of Technical Agriculturalists. The session was adjourned at twelve o'clock.

The report of the Resolutions Committee was presented by the Chairman, W. F. Hanna, on Friday afternoon, July 28. The adoption of the report was moved by W. F. Hanna, seconded by W. F. Greaney, and was carried unanimously.

SCIENTIFIC SESSIONS.

Five sessions devoted to the reading of scientific papers were held from July 25 to 28. For two of the sessions the Society met jointly with the Agronomists. At these, nearly all the papers were on some phase of cereal breeding; several dealt more specifically with the inheritance of disease resistance. One paper by H. B. Humphrey, entitled "Cereal Disease Forecasting", was given at a joint session and is here reprinted.

At its own sessions twenty papers were read. Seventeen of the papers are reprinted in this Proceedings from the Proceedings of the World's Grain Exhibition and Conference, Vol. 2, 1935, and are by the following authors: T. Johnson and Margaret Newton; F. J. Greaney (one paper and one abstract, full text of latter in Sci. Agric. *14:* 496-511. 1934); W. Popp; W. F. Hanna and W. Popp; G. W. Padwick and A. W. Henry; J. F. Dastur; W. Popp and W. F. Hanna (abstract, full text in Sci. Agric. *15:* 424-434. 1935); M. W. Cormack; P. M. Simmonds and B. J. Sallans; H. W. Mead; L. E. Tyner; W. C. Broadfoot (two abstracts, full texts in Can. Jour. Res. *10:* 95-114 and 115-124. 1934); G. B. Sanford and M. W. Cormack; and T. C. Vanterpool (two papers). The titles of these papers may be learned by consulting the Table of Contents.

The two following communications were read and have appeared elsewhere as follows:—

Hurst, R. R., Observations on the brown heart disease of turnips.
Sci. Agric. *14:* 679-686. 1934.

Jones, W., Soft rot of potatoes caused by *Pythium ultimum* Trow.
Sci. Agric. *15:* 402-410. 1935.

An abstract entitled, "Soil treatment in the control of certain potato and turnip diseases", by D. J. MacLeod was the only other communication read.

REPORT OF THE SECRETARY-TREASURER.

Mr. President:

I beg to submit herewith the report of the Secretary-Treasurer for the fiscal years 1931-32 and 1932-33.

The period under review has been a most difficult one for the Society. In common with other organizations the economic depression has resulted in reduced membership and in the slow collection of fees. In addition the withdrawal of government support necessitated an unfortunate but unavoidable delay in the publication of the "Proceedings" of the 1931 meeting and the abandonment of the 1932 meeting. However, it is felt that progress has been made, that the remaining members are those most keenly interested in the organization, and that the financial position is reasonably sound. With the return of better economic conditions the Society will be in a position to move forward.

Publication of "Proceedings."

The details of the negotiations leading up to the publication of the 1931 "Proceedings" need not be discussed in this report. Suffice to say that finally in the fall of 1932, arrangements were completed whereby the "Proceedings" were published in "Scientific Agriculture" as separate papers. These papers will be bound together with the business section and issued in a form similar to those of 1930. The cost was reduced to a very low figure and the Society is indebted to the General Secretary of the C. S. T. A. for co-operation in this matter.

Amendment to the Constitution.

In accordance with a motion passed at the Guelph meeting a mail ballot was conducted with regard to the amendment of Article VI of the Constitution. The amendment was adopted unanimously.

Election of Officers.

In view of the postponement of the 1932 meeting, Council determined to suspend Article V of the Constitution and leave the election of officers until 1933. An election was held in the spring of 1933 in accordance with articles V and VI (amended). Nomination ballots were sent out on April 1, to be returned on or before April 30. A total of 28 ballots were returned, resulting in the nomination of Messrs. D. L. Bailey, J. Dearness and J. E. Howitt for President; Messrs. G. H. Berkeley, J. H. Craigie, and P. M. Simmonds for Vice-President, Messrs. G. R. Bisby, I. L. Conners and N. A. MacRae for Secretary-Treasurer, and Messrs. J. G. Coulson, H. T. Güssow and J. F. Hockey for Councillor. The electoral ballots were mailed on May 2 to be returned on or before May 31. In all 61 ballots were returned, resulting in the return of Messrs. D. L. Bailey, J. H. Craigie, I. L. Conners and H. T. Güssow to the offices of President, Vice-President, Secretary-Treasurer and Councillor respectively. Dr. Irene Mounce and Mr. A. W. McCallum acted as scrutineers.

Membership.

Since the last meteing four members have resigned, and no new applications for membership have been received. Fourteen members have not paid their fees for the year 1931-32 and have been tentatively suspended, pending action at the present meeting. Excluding the above, the membership of the Society numbers 125.

The Third (Regina) Meeting.

Plans for the present meeting were, with the approval of the President, placed in the hands of a local committee under the chairmanship of Dr. P. M. Simmonds. The committee has worked in conjunction with the officials of the World's Grain Exhibition and the C. S. T. A.

Finances.

As shown by the attached financial statements total revenue for the two fiscal years 1931-32 and 1932-33 amounted to $310.31, together with a cash balance of $625.13 brought forward. Total expenditures amounted to $93.00 leaving a net balance on May 31, 1933 of $842.44. From this balance a payment has yet to be made to the C. S. T. A. covering the publication of 1931 Proceedings. Of the 1931-32 fees, 48 are still outstanding, while six members have paid their 1933-34 fees in advance.

Acknowledgments.

The Secretary-Treasurer desires to express his appreciation of the assistance and co-operation rendered by various members of the Society, particularly to the Assistant Secretary-Treasurer, Mr. N. A. MacRae.

Respectfully submitted,

(*Signed*) T. G. Major,
Secretary-Treasurer.

May 31, 1933.

FINANCIAL STATEMENT.

CASH ACCOUNT.

1931-32.

REVENUE:			
Balance brought forward		$625.13	
Fees: Regular —29 @ $3.00	$87.00		
Student — 7 @ $1.00	7.00		
		94.00	
Bank Interest		17.15	
Exchange on cheques		.45	
Premium on U.S. funds		.54	
			$737.27
EXPENDITURE:			
Annual meeting sundries		8.65	
Printing and stationery		25.17	
Stenographic services		10.00	
Telephone, telegraph and postage		20.44	
Library		3.25	
Exchange on cheques and stamp tax		.81	
			68.32
Balance in hand May 31, 1932			$668.95

CASH ACCOUNT.

1932-33.

REVENUE:			
Balance brought forward		$668.95	
Fees: Regular —56 @ $3.00	$168.00		
Regular — 1 partial	2.00		
Student — 6 @ 1.00	6.00		
		176.00	
Bank Interest		19.70	
Exchange on cheques and stamps		.46	
Premium on U. S. funds		2.01	
			$867.12
EXPENDITURE:			
Stenographic services		$10.00	
Postage		10.00	
Exchange on cheques and stamp tax		1.68	
Returned cheque		3.00	
			$24.68
Balance in hand May 31, 1933			$842.44

REPORT OF THE RESOLUTIONS COMMITTEE.

The Resolutions Committee respectively submit the following resolutions:— Be it resolved that:—

(1) Whereas the success of our Third Annual Meeting, held at Regina, Saskatchewan, from July 25 to 28, has been due, in a large measure, to the generosity of the President and Staff of Regina College in placing at our disposal the facilities and privileges of that institution, we express to the President and Staff of the College our sincere appreciation of their kindness and hospitality.

(2) Whereas this Society has held its Third Annual Meeting at Regina, Saskatchewan, in conjunction with the Canadian Society of Technical Agriculturists and affiliated societies, and whereas members of our Society have had the privilege of attending the meetings of these societies, and of hearing the special lecturers who had been invited to address their meetings, we express to the executive of the Canadian Society of Technical Agriculturists our sincere appreciation of the benefits that we have derived from meeting with them.

(3) Whereas this Society has held its Third Annual Meeting at Regina, Saskatchewan, in conjunction with the World's Grain Exhibition and Conference, and whereas the members of our Society have derived much benefit from the special lectures and valuable discussions which have been arranged by the conference, and from the instructive exhibits which have been gathered from many parts of the world, we convey to the Chairman of the Programme Committee of the World's Grain Exhibition and Conference, our sincere appreciation of the opportunity that has been given us to participate in the Conference activities.

(4) Whereas it has been conveyed to the Society that our new President, Dr. D. L. Bailey, was unable to be present on account of the distressing motor accident in which Dr. Bailey's parents sustained serious and painful injuries, we express to him our sincere sympathy, and our earnest hopes for a rapid convalescence of his parents.

(5) Whereas it has come to our knowledge that Dr. John Dearness, an honoured member of this Society, has undergone a serious operation and is now making a satisfactory recovery, we convey to him the good wishes of our membership and the sincere hope that he will soon be restored to good health and enabled to resume his valuable activities in the field of mycology.

(6) Whereas the late Prof. Arthur Jaczewski, the eminent Russian mycologist and plant pathologist, was an honorary member of the Canadian Phytopathological Society, we instruct our Secretary to write Madame Jaczewski expressing our sympathy to her.

(7) Whereas the members of this Society at its Third Annual Meeting have had the privilege of hearing the valuable papers presented by two outstanding American scientists, Dr. H. B. Humphrey and Dr. J. A. Clark, and of benefiting by their instructive discussion of other papers, we express our pleasure in having had them meet with us, and express the hope that they may be able to attend future meetings of the Society.

W. F. Hanna, *Chairman.*
J. H. Craigie
P. M. Simmonds
I. L. Conners

II. PHYTOPATHOLOGY

CEREAL DISEASE FORECASTING

HARRY B. HUMPHREY[1]

It is but human to try to account for whatever dire circumstance may befall us. Nowadays, we seek the cause of accident or calamity in some event or chain of events that seems logically to account for it. We investigate and at great pains and no little expense we carry on research in an effort to get the facts about every sort of phenomenon affecting human welfare and progress. But it has not always been so. Even to-day there are some among us who freely and positively predict that if potatoes are planted during the "wrong" phase of the moon they will not thrive and the crop will be a near failure. There are those who believe that if clover is not cut in the "right" phase of the moon it will become moldy and rotten in the mow. Only five years ago an island farmer of the Pacific Northwest sought my advice concerning his potato field that had become "sick" and most unpromising because, as he stated, he had planted it in the "wrong stage of the moon".

There are among us, even yet, those who attribute epidemics of rust and smut to the wrath of God visited upon the wicked and the unjust because of their unbelief and their perversity. Such as these continue to predict without the slightest hesitancy and are not abashed by the fact that these occasional visitations of "blight and blast" fall upon the devout as well as the wicked.

The better informed are much inclined to view with amusement the predictions and dogma of those who seek in the realm of the supernatural the causes of disaster to our crops. We appreciate the truth uttered by former Justice Oliver Wendell Holmes when he said: "Certitude is not the test of certainty. We have been cocksure of many things that were not so." The critical observer and experimenter knows, however, that bunt-contaminated seed wheat, sown in soil maintained at proper moisture and temperature conditions, very probably will produce a bunt-infested crop. Even before the dawn of the present day of scientific enlightenment many observing New England farmers were predicting with reasonable accuracy the probable seasonal occurrence of rust in their wheat not because of the wrath of God but because of some suspected connection between the rust they periodically observed on the common barberry of their hedges and its subsequent appearance in their wheat. Legislation, calling for the destruction of the barberry in certain of the New England Colonies, was enacted more than a century before de Bary's discovery of the relation of the barberry to the life cycle of stem rust.

With the rapid development of our present knowledge of cereal diseases, based as it is on well-laid foundations of careful observation and research, it would seem that we should be able to predict with reasonable assurance of confirmation when the farmers of any given region may experience an epidemic of stem rust, of scab, of bunt, or of corn smut. Knowing, as we do, some of the cardinal conditions incident and necessary to wholesale outbreaks of these diseases, we are now, in fact, in a position from which to offer occasionally helpful advice to those who most need it.

It is true, however, that, as "with the best laid schemes o' mice an' men", our most carefully conceived predictions as to the appearance of this or that cereal disease "gang aft agley", and we are reminded that we do not yet know all of the facts essential to safe prophecy. If I sow bunt-contaminated wheat of a susceptible variety in properly aerated soil and under conditions of soil moisture and temperature that would seem to promise a maximum of smut, I may yet harvest an all but bunt-free crop. One might predict with reasonable certainty that the crop

[1] *Principal Pathologist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture, Washington, D.C., U.S.A.*

under such an initial handicap would be full of bunt, and yet, for some unknown reason, little or none may develop. Failure to obtain bunt under such seemingly optimum conditions for infection has been attributed by some not so much to escaped infection as to the plant's rapid growth and consequent ability to outdistance the bunt organism in its race to fruition. Others are inclined to the somewhat more tenable assumption that we have here a genuine infection failure because of an antibiotic condition set up in the soil, traceable possibly to some organism, bacterial or fungoid, that has either a particular affinity for the bunt fungus or is capable, by means of the by-products of its metabolism, of setting up certain antagonisms for the smut organism.

I well remember with what apparent finality the farmers of the Palouse Country in the State of Washington were told from the public platform and through sincere and well-intended letters and experiment-station circulars that they could grow clean, bunt-free wheat if they would but adopt the recommended methods of seed treatment. It eventually was shown by the farmers themselves that such prediction was, for the Palouse Country at least, thoroughly unsafe. It might be relied upon in Kansas or Minnesota or Ohio, but not so in eastern Washington and the Idaho Panhandle. It is now, of course, a well-known fact that the Palouse farmer's time-honored system of summer-fallowing, aided and abetted by his practice of combine harvesting and by the long rainless summers, makes his escape from bunt all but impossible so long as smut-susceptible varieties of wheat are sown. It requires only to follow a "combine" on its way around a field of bunt-infested wheat to convince one of the reality of the smut shower. Countless billions of smut spores thus set free settle, every summer, into the surface soil of fallow acres that are to be sown in September or early October. And now we can predict with more than average safety that, given a smutty harvest, fallow fields, and smut showers under conditions such as obtain in eastern Washington, there will be crops of bunt until there is universal adoption of varieties that are highly resistant to this kind of smut. It is, of course, possible that we may some day discover a method of soil sanitation or fungicidal treatment by means of which infection from bunt spores present in the soil may be prevented. In such an event bunt-susceptible varieties of wheat could still be sown and we could rest assured that the crop would be smut-free provided the requisite sanitary practices were carried out.

But, it is now known that even such prophecy is no longer bomb-proof. Our plant breeder, happy in the realization of his victory, gets a rude awakening when some plant pathologist announces the discovery of a new physiologic form or race of the bunt fungus that attacks with ease his hitherto highly-resistant variety of wheat. Possibly it is vain to predict that we shall eventually bring forth one or more varieties of wheat that will be proof against all physiologic forms of the bunt fungus; but, even so, the work of the plant breeder should be permitted to go on unabated, for new and better varieties of wheat will long be in demand, not so much from the standpoint of increased production as from that of economy of production.

And what may we say by way of prediction concerning epidemics of the other cereal smuts? Is it safe to predict that seed wheat from a field showing as much as ten per cent of loose smut will produce an equally smutty crop the following harvest? Can we safely assume that it will produce even one per cent? Obviously, we cannot unless we were fortunate enough to be on the ground at the time the crop from which such seed came was in bloom. If, at that time, the conditions for the distribution and germination of the smut spores were optimum we could safely predict as much or more smut in the next year's crop. If, on the other hand, the relative humidity during the critical period was abnormally low, we could predict almost certainly that the next year's crop would show less than ten per cent of its heads smutted. Again, we may predict with reasonable certainty that, no matter how badly smut-infected the seed, it will produce an essentially smut-free crop provided that, before sowing, it be given the recommended hot-water treatment.

The severity of certain smuts may become cumulative if seed treatment be neglected. This is particularly true of the smuts of oats and the covered smut of barley. Thus it is safe to predict that, given optimum soil-temperature and moisture conditions, these smuts will take a certain percentage of the crop produced by smut-infested, non-treated seed. If such seed be sown year after year we should not be surprised to find more and more smut in succeeding crops.

Corn smut, on the other hand, presents a quite different picture. Here, seed treatment is of no avail, for we are not dealing with a seed-borne fungus. And yet, it is possible within certain limits to predict the probable occurrence and severity of this smut. It is an oft-observed fact that in regions and seasons of less than the average rainfall during the growth period for corn from fifty to one hundred per cent of all the plants in a field may bear smut. Under conditions of abundant rainfall, all other conditions being the same, one could safely predict the occurrence of considerably less infection. The reason for this difference is not far to seek. The smut spores, present in the loose, easily transported dust, find their way into the bud water at the base of every leaf sheath and in the terminal leaf whorl. There, under satisfactory conditions for incubation, they germinate and infection of the tender meristematic tissues of incipient ears or tassels or leaves may readily occur.

Again, if corn be grown continuously, year after year, on the same land, one may safely predict the recurrence, if not an actual increase, of smut in successive crops, varying in amount and severity with the frequency of rainfall during the growing season and the amount of smut-laden crop refuse in and on the soil.

The temptation to predict epidemic outbreaks of plant disease probably is in no case so intriguing as in that of the cereal rust. Instance, for example, the seemingly ever-present and mobile stem rust, which tarries awhile on the barberry, only to spread far and wide to growing fields of grain, or rides aloft on the winds from Texas and Oklahoma only to find lodgment later in the lush expanse of wheat to the north. Stem rust would seem to offer a fertile and sure field for the prognosticator, and particularly so, now that we know, or believe we know, the conditions that determine whether and when this pest is due to arrive in epidemic form. And yet, with the stage all set for disaster, we have, more than once, awakened only to find the scene shifted, the threatened far-flung epidemic of stem rust thwarted in its advance, and our prowess as prophets definitely checked if not actually discredited.

Only last summer the rust-wise were predicting in early July a general epidemic of stem rust of wheat in the Dakotas and the Provinces of Manitoba and Saskatchewan. Infection had spread from the states to the south, or had come in from not too distant barberry bushes, and was observed in South Dakota as early as June 14. By the 10th of July it had become fairly general in the eastern counties of that State and was present in North Dakota throughout the length of the Red River Valley. The weather, until July 8, had been humid and sufficiently warm to promote the maximum growth and spread of rust. All conditions incident to the rapid development of a destructive epidemic were present and its arrival seemed inevitable. But, overnight, as it were, conditions changed. The weather suddenly turned excessively hot and windy, with the result that in less than a week much of the spring grain throughout eastern South Dakota had prematurely ripened. The conditions were all against the continued development of rust and there was no further increase of it except in the north-eastern counties of North Dakota where much of the wheat (durum) was late and where there had been more frequent rainfall.

The American wheat crop of 1915 has gone down in history as the greatest ever produced in the United States, it having reached the grand total of more than a billion bushels. The growing season was unseasonably cool; hence the development of rust was inhibited and that of the wheat was enhanced. The following summer (1916) was in every respect a rust promoter. The weather was warm and there was an abundance of moisture. Stem rust got under way early and by mid-July every condition for a terrific epidemic had been fulfilled. In less than a fortnight the

newspapers of the spring-wheat States were running front-page columns describing the fate that had befallen the farmers of those States, a fate, too, that did not spare the farmers of the three Prairie Provinces of Canada.

Knowing what we do now concerning the factors affecting the development and spread of stem rust we probably could have predicted two or three weeks in advance, and with average accuracy, the ultimate intensity and scope of the epidemic of 1916. I doubt whether the same would apply regarding any prediction one could have ventured in 1915. There was stem rust in the spring wheat that summer. All it needed was a few hot, muggy days and nights and the potential feast would have been turned to a famine. Doubtless there were those who feared and predicted a devastating epidemic, but the weather ruled otherwise.

It takes more than weather and a growing, rust-susceptible crop to create a devastating outbreak of rust. There must be an abundance of inoculum either from infected barberries or from regions farther south where the rust survives the rigours of winter. Not a year passes but that some rust from either one or both sources finds its way into the spring-wheat area, but it sometimes happens that it is not present in sufficient amount to produce an epidemic. So long as we have with us these sources of inoculum the accuracy of any prediction one may make concerning the extent and severity of stem-rust epidemics in that territory will depend upon the amount of initial inoculum available, the weather conditions, and the rust susceptibility of the crop. If and when varieties of wheat and other cereals shall have been brought out and adopted that are highly resistant to the more generally prevalent physiologic forms of stem rust, then the chances of trustworthy prediction will have become very considerably improved.

What of the other cereal rusts? Can we safely predict for any crop season the incidence of an epidemic of the leaf rust of wheat or the crown rust of oats? Under certain conditions, yes; if one or more of those conditions be wanting, no. Leaf rust requires no barberry or other bush for its propagation and spread. Its cold-resistance enables it to survive wherever its host can weather the rigours of winter. It is a prodigious producer of summer spores that spread abroad on every passing breeze or rise on convection currents to elevations as great as three miles or more only to be brought down by rain, as are the spores of other rusts, over a region a thousand miles distant from their points of origin. Its ubiquity and its almost ceaseless and prolific spore production offer fairly safe guarantees of its continued existence in recurrent epidemic form. In the event of a heavy or even a moderate amount of autumn incidence of leaf rust the prognostic observer may safely announce the coming of an epidemic, provided that the approaching crop season be a normal one. If, however, the temperature of the following spring and early summer be abnormally low or a drought prevail during May and early June, his prediction may fail.

Crown rust of oats, like stem rust, can and does strike at the farmer of the Middle West from a double base of supply and attack, namely, the rust-infested fields to the south and its alternate host, the buckthorn, in the north. It so happens that in those states where oat production is most extensive the greatest population of susceptible buckthorn abounds. Scarcely a year passes that does not record its infection by crown rust and just as often does this shrub contribute its share to recurrent epidemics of rust. It is safe to predict that until the buckthorn is eradicated and rust-resistant varieties of oats are generally adopted he who has a nose for scenting forthcoming outbreaks of crown rust may remain reasonably certain of the soundness of his forecasting.

The one cereal rust in North America that has exercised its jinks to the confusion if not embarrassment of the supposedly rust-wise clairvoyant is stripe rust. Some of us still recall with what consternation its discovery in the Far West was heralded. A few of us had the temerity to believe back in 1915 and 1916 that it would be a matter of only a few years when this rust would be an established and destructive disease in the great wheat-producing areas of North America. The thing predicted has not happened, and those most familiar with the life and migratory

habits of the rusts are at a loss to explain why stripe rust, known certainly to have been in the United States and probably Canada since 1892, has failed to appear east of about 102½ degrees W. longitude. It would seem that this rust, common as it is to so many of our wild grasses, as well as to wheat, barley, and rye, should have found its way easily and promptly to the great wheatfields of Manitoba, the Dakotas, Nebraska, and Kansas. It has, however, extended its range but little beyond those states and provinces where it was known to occur a decade or more ago.

What is even more difficult to understand is our failure to find stripe rust on wheat in Texas and Oklahoma, so immediately in line to receive it directly from infected fields in northern Mexico. There is circumstantial evidence to show that summer spores of stem rust travel from Mexico into Texas and thence northward to the wheatfields of Manitoba and Saskatchewan. If this be true of the spores of stem rust, why should it not be equally true of those of stripe rust? Is it too much to predict that we shall yet know the answer? Someone has aptly said "art is long"; so also is science and its tireless search for the reason why.

Perhaps no group of cereal diseases seems more puzzling to the prognosticator than does that comprising the foot and root rots of cereals and particularly those of wheat. This is doubtless due to the fact that there yet remains very much for us to learn concerning these several maladies, much to uncover as to the particular climatic and soil conditions that promote their development. And yet, it is reasonable to predict that as long as the farmers of the Judith Basin in Montana continue to sow their winter wheat in late summer just so long will they pay excessively for it through the tolls exacted by *Helminthosporium* foot rot.

It may be, also, that we shall some day discover a more than accidental relation between certain foot and root rots of cereals and the chemical condition of the soil. Already, we have trustworthy evidence of such relationship between certain mineral deficiencies and the root and stalk rots of maize, and there is some reason to believe that the phosphorus deficiency characteristic of certain of our midwestern prairie soils may be a fundamental factor in the too general incidence of a familiar foot rot in the spring-wheat area.

Another cereal disease of major importance to our midwestern farmers and more especially to those of the Corn Belt is the well-known scab of wheat and barley. It attacks rye, also, but rarely with that severity suffered by the first-named crops. It is only fifteen years ago that the very important discovery was made disclosing the fact that the scab fungus and one of the root and stalk rot fungi of corn were one and the same organism. This discovery has been of the greatest significance in the control of scab and has been a boon to those who wish to grow barley and wheat of the greatest market value.

It is now certainly known that the still too-current practice of sowing wheat and barley on disked corn land where there is unavoidably an excess of cornstalk litter is a dangerous one. All such litter is very apt to be a potential source of scab inoculum, which, under optimum conditions for the further growth and maturity of the spores of the fungus, will be discharged from the corn refuse into blossoming heads of grain where and when they are most vulnerable. We do not experience a scab epidemic every summer, but when such a one comes upon us as marked the crop season of 1929 it suffices to rock the market boat and convince us that scab is at once a disease and a challenge. While there yet remains something to be learned about the scab fungus, we know enough of its life history and habits to forecast with more than average certainty an oncoming epidemic of the disease and are sufficiently sure of our facts to advise the farmer helpfully in his efforts to escape its ravages and save his wheat and barley from utter ruin.

And now, what of the future? How shall we improve our "batting average" in the field of cereal-disease forecasting? Or shall we turn to other and more fruitful endeavor? Someone has said: "Prophecy is always dangerous and often profitless. But prediction is the purpose of all science. . .Only by prophecy, then, can we escape the charge of futility".

It would seem that any successful system of crop forecasting must in ever-growing measure be based upon the dependable prediction of disease epidemics by those who are most fully and scientifically informed of the facts that relate to the various causative agents and the factors affecting their behaviour and distribution. Such forecasting should by no means be left to the half-informed or the *poseur*. We have in the past witnessed enough of the work of false prophets whose word sufficed to "bull" the wheat market to the tune of six or eight cents per bushel and paralyze with useless fear the optimism of a million farmers, hopeful of a bountiful harvest.

Plant breeders and pathologists everywhere need more than ever to apply themselves to the task of producing disease-resistant varieties of wheat, of oats, of corn, and of every crop necessary to human economy. Better seed, better tillage, a more systematic and scientific crop and soil sanitation, and the extension of information concerning the prevention of plant disease will go far to reduce crop hazards and will certainly fortify the position of the forecaster.

In conclusion, I would emphasize the fact that the development of any of the cereal diseases discussed in the foregoing pages, whether in epidemic form or not, is contingent upon certain conditions. There must, first of all, be sufficient inoculum to provide a more than local outbreak. But, regardless of the amount or virulence of the inoculum, there can be no general epidemic if one or more of the conditions necessary to its development are absent. For example, we may have an abundance of stem-rust inoculum showered upon growing fields of susceptible wheat at a time when temperature, light, and soil-moisture conditions are optimum for growth and spread of the rust fungus, yet, if the nights be cloudy or windy during the critical period of the crop, there will be no dewfall, and hence, little or no rust. The simultaneous occurrence of all conditions incident to an outbreak means the development of an epidemic, barring unknown contingencies.

Reliable predictions regarding the occurrence of any plant disease, therefore, depend upon a full and accurate knowledge of the conditions necessary to its development. Since weather factors enter so importantly into this aspect of crop and disease production, any prediction must be conditioned to meet the vagaries of the weather. With every scientific aid at our command we are yet unable to forecast the weather with daily certainty of expected behaviour. Our success in cereal-disease prediction, therefore, must be based on that of the weather forecaster as well as on the plant pathologist's knowledge of the facts that relate to disease outbreaks.

HYBRIDIZATION BETWEEN *PUCCINIA GRAMINIS TRITICI* AND *PUCCINIA GRAMINIS AVENAE*[1]

THORVALDUR JOHNSON AND MARGARET NEWTON[2]

Puccinia graminis Pers. is divided into several physiologic races on the basis of physiological differences which can be detected by means of infection studies on cereals and grasses. As *Puccinia graminis* has been shown to be heterothallic (*1*, *2*, *3*) and as its physiologic races, with one exception, possess a common alternate host (*Berberis vulgaris L.*), there is good reason to consider inter-racial crossing as one of the possible sources of new strains of stem rust. Crosses which have already been made between *Puccinia graminis tritici* Erikss. and Henn. and *Puccinia graminis secalis* Erikss. and Henn. (*4*, *5*, *7*, *8*) have produced F_1 progeny which, strictly speaking, conforms to neither of these races. Similarly, in a cross between *Puccinia graminis tritici* and *Puccinia graminis agrostidis* Erikss. (*4*), an F_1 hybrid has been obtained which differs from both of the parental races.

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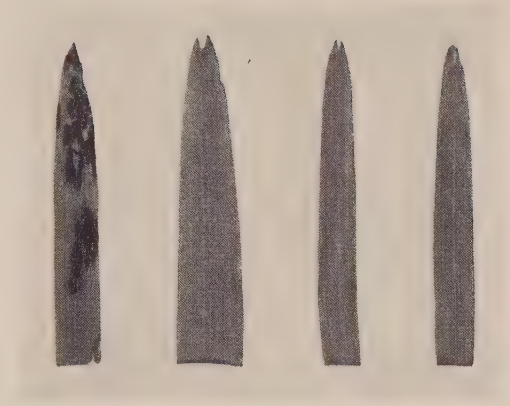

FIGURE 1. *Types of infection produced by P. graminis avenae form 6 on (left to right) Victory oats, Success barley, Little Club wheat and Liguleless wheat.*

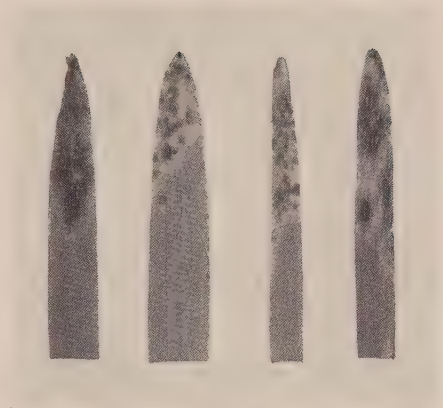

FIGURE 2. *Types of infection produced by the tritici-avenae hybrid rust on (left to right) Victory oats, Success barley, Little Club wheat and Liguleless wheat.*

FIGURE 3. *Types of infection produced by P. graminis tritici form 9 on (left to right) Victory oats, Success barley, Little Club wheat, and Liguleless wheat.*

The cross between *Puccinia graminis tritici* and *Puccinia graminis avenae* Erikss. and Henn., which is reported in the present paper, represents the first successful attempt to cross these two races.

One of the objects of a cross such as that described in the present paper is to secure a hybrid rust whose pathogenicity may be compared with the pathogenicity of the parental rust strains. Such a comparison cannot be made with any degree of exactitude unless the parental rust strains are known physiologic forms. In the present cross the parental forms used were *Puccinia graminis tritici* form 9 and *Puccinia graminis avenae* form 6. The breeding behaviour of both parental forms was investigated by means of selfing studies; that is, barberries were infected by each form and the resulting aecia were used to establish uredial cultures which were identified according to the standard procedure of determining physiologic forms. Form 9, as in all previous selfing studies, proved homozygous, all its progeny being identified as *P. graminis tritici* form 9. Form 6, however, was in a heterozygous condition, as is shown by the fact that three forms of *P. graminis avenae*, forms 4, 6 and 7, appeared in its progeny.

The crossing technique employed in these experiments is almost identical with that used in previous experiments (*6*) in which crosses were made by applying the pycniospore-containing nectar of a haploid pustule of one physiologic form to several haploid pustules of another physiologic form. As previous experience with inter-racial crosses had shown that very few of the nectar-receiving pustules formed hybrid aecia, it was thought advisable, in these crosses, to apply the collective nectar of several pustules of one parental form to each haploid pustule of the other parental form so that each pustule might receive nectar from pustules of both sexes. Such a procedure, when employed in crosses between physiologic forms of the *tritici* race results in aecial formation in practically all of the nectar-receiving pustules. This method should therefore materially increase the chances of aecial formation in inter-racial crosses.

In the crossing experiments, thirteen haploid pustules of *P. graminis avenae* form 6 received nectar from pustules of *P. graminis tritici*. Of these, eight pustules received nectar of the *tritici* form 36, four received nectar of form 11, and one received nectar of form 9. Only one of the thirteen nectar-receiving pustules formed aecia which, however, failed to cause infection on wheat or oat seedlings. One of the pustules produced rudimentary aecia which did not break through the epidermis.

Nectar of *P. graminis avenae* form 6 was applied to twelve haploid pustules of *P. graminis tritici* form 9, three haploid pustules of form 11 and four haploid pustules of form 36. Of the nineteen nectar-receiving *tritici* pustules, seventeen failed to produce aecia, one produced rudimentary aecia, and one developed aecia of normal appearance. These aecia, which were formed in one of the pustules of form 9, were picked off singly and the contents of each aecium were then used to inoculate a seedling leaf of Little Club wheat and one of Victory oats. Infections developed on both varieties. Six cultures were established, each originating from a single aecium. It was evident from the ability of the rust to attack both Victory oats and Little Club wheat that a *tritici-avenae* hybrid had been obtained. Tests were therefore undertaken to determine the range and degree of pathogenicity of the hybrid form on wheat, oats, barley and certain grasses.

The six hybrid cultures proved identical in pathogenicity. The results of the infection studies are shown in Table 1 in which are also included the infection types produced on the same hosts and at the same time by the two parental forms. The infection types produced on Victory oats, Success barley and two wheat varieties by the parental forms and the hybrid rust are illustrated in Figures 1, 2 and 3.

An examination of the above-mentioned table and figures will make it clear that the hybrid rust has inherited certain of the pathogenical characteristics of both its parental forms. From the oat rust parent it has inherited the ability to

attack the oat varieties Victory, White Russian and Richland and the grasses *Dactylis glomerata* L. and *Phalaris canariensis* L. From the wheat rust parent it has inherited the ability to attack the wheat varieties Liguleless and Little Club,

TABLE 1.—*Average infection types of the tritici-avenae hybrid form on cereals and grasses.*

	Infection types produced by		
	Tritici-avenae hybrid	*P. graminis tritici* form 9	*P. graminis avenae* form 6
OATS			
Victory	3±	0;	4
White Russian	3–	0;	4
Richland	3–	0;	4
Joanette Strain	1	0;	4–
WHEAT			
Little Club	X	4	0;
Marquis	0;	4–	0;
Marquis × Kanred	0	0	0
Kota	0;	3++	0;
Arnautka	0;	4–	0;
Mindum	0;	4=	0;
Speltz Marz	0;	4=	0;
Kubanka	1	4=	0;
Acme	0;	3++	0;
Einkorn	0;	3+	0;
Vernal	0;	4=	0;
Khapli	0;	1–	0;
Liguleless	3±	4	0;
BARLEY			
Success	X	3	1–
Manchurian	X	3	1–
O.A.C. 21	X–	X	0;
GRASSES			
Agropyron cristatum	0;	0;	0;
Agropyron tenerum	1 to 2	2	0;
Bromus inermis	0	0	0
Dactylis glomerata	3	0;	3
Festuca elatior	0;	0	2
Hordeum jubatum	1	3	0
Lolium sp.	0; to 1	0;	0; to 1
Poa pratensis	0;	0	0;
Phleum pratense	0;	0	0;
Phalaris canariensis	3	0;	3+

Explanation of symbols:

0—absolute immunity
1—high resistance
2—moderate resistance
3—moderate susceptibility
4—complete susceptibility

X—indeterminate type of infection
(;)—hypersensitive flecks
(++), (+), (–), (=) indicate quantitative variations in the above-mentioned types.

the three barley varieties tested and to a certain degree such grasses as *Agropyron tenerum* Vasey and *Hordeum jubatum* L.

Because the hybrid rust possesses some but not all of the characteristics of each of the parental forms a certain degree of intermediacy is expressed in the pathogenical behaviour of the hybrid. This intermediacy becomes evident, first, through a consideration of the infection types produced by the hybrid rust on its host varieties and, second, through a comparison of its host range with the combined host ranges of the parental forms.

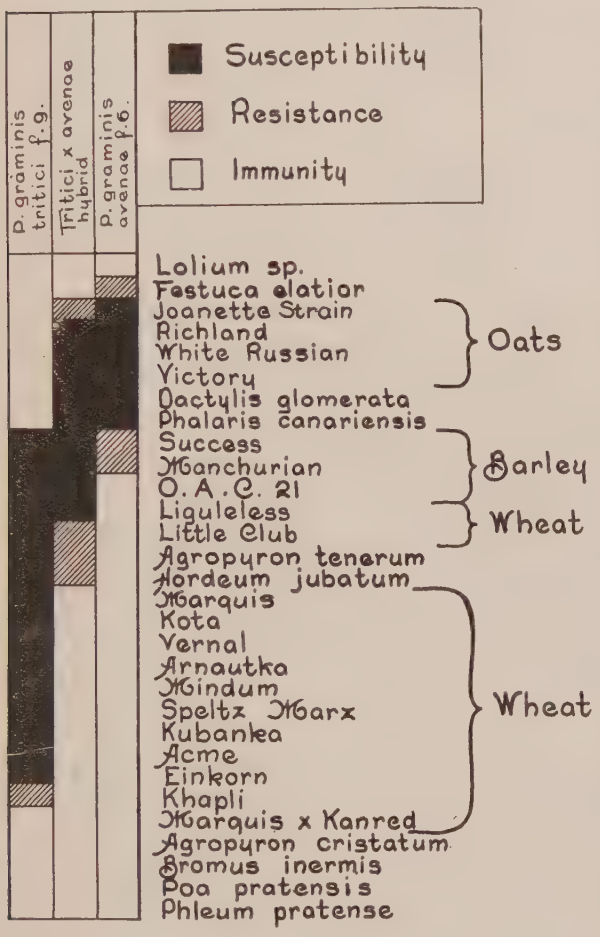

FIGURE 4. *A diagrammatic representation of the range of pathogenicity of the tritici-avenae hybrid rust and its parental forms on certain cereals and grasses.*

A comparison of the infection types of the hybrid rust (Table 1) with those of the oat rust parent shows that not one of those natural hosts of oat stem rust which were tested, with the possible exception of *Dactylis glomerata*, is attacked as severely by the hybrid rust as by the oat rust parent. The same relationship holds when the infection types of the hybrid rust on natural hosts of wheat stem rust are compared with those of the wheat rust parent.

The intermediacy of the hybrid rust is likewise evident when the range of pathogenicity of the hybrid is compared with the combined host ranges of the two parental forms (Figure 4.). The host range of the hybrid form is somewhat narrower on oat varieties than is that of the oat rust parent, and is decidedly narrower on wheat varieties than that of the wheat rust parent.

In its capacity to attack certain of the host varieties of both of the parental rusts this hybrid resembles the *tritici-secalis* hybrid rust described by Levine and Cotter (*5*), which is reported to attack some varieties of wheat and rye as well as barley.

DISCUSSION

In a previous paper (*4*) it was pointed out that a certain degree of inter-sterility was apparent in crosses between physiologic races of stem rust. This was particularly true of crosses between *Puccinia graminis tritici* and *Puccinia graminis agrostidis*. That the same situation prevails in crosses between the *tritici* and *avenae* races is indicated by the fact that aecia were formed in only one of the nineteen nectar-receiving *tritici* pustules and in only one of the thirteen nectar-receiving *avenae* pustules. The lack of complete inter-fertility between the physiologic races

of stem rust is perhaps the reason for the pathogenic distinctness of these races from each other. If any appreciable degree of inter-fertility existed, it is likely that there would frequently be found, in nature, hybrid rust strains which could not readily be classified as physiologic forms of one or another of the accepted physiologic races.

Since, however, crosses between the *tritici* and the *avenae* races can be made under experimental conditions, it is not improbable that they may also occur occasionally in regions where the two rusts occur together in proximity to their common alternate host, the barberry. Such crosses, however, must be rare since no rust appears to have been collected which shows indications of *tritici* x *avenae* origin.

Furthermore, if it is permissible to generalize from the pathogenic character of the *tritici-avenae* hybrid rust and the *tritici-secalis* and *tritici-agrostidis* hybrid rusts described previously (*4*), it may be expected that inter-racial hybrid rusts would be low in virulence on most cereals and grasses. Their lack of virulence might then be an important factor in preventing their spread and establishment as permanent parasites of cereals.

Summary

1. A cross has been made between *Puccinia graminis tritici* form 9 and *Puccinia graminis avenae* form 6. The hybrid aecia originated in a pustule of form 9 to which pycniospore-containing nectar of form 6 had been applied.

2. The hybrid rust has certain of the pathogenical characteristics of both of the parental rusts. From the *tritici* parental form it has inherited the ability to attack—though to a rather limited degree—certain wheat and barley varieties. From the *avenae* parental form it has inherited the capacity to attack certain varieties of oats and some of the grasses which are natural hosts of oat stem rust. The pathogenicity of the hybrid form on wheat varieties is, however, much more limited in both range and virulence than that of the *tritici* parental form, and similarly its pathogenicity on oat varieties is somewhat limited in comparison with that of the *avenae* parental form.

3. The crosses furnished evidence of a low degree of inter-fertility between the *tritici* and *avenae* races.

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METHOD OF ESTIMATING LOSSES FROM CEREAL RUSTS[1]

F. J. GREANEY[2]

INTRODUCTION

Cereal rusts annually cause enormous economic losses in Canada and the United States (*1*, *4*, *5*). The nature of the loss is twofold: first, a direct loss in yield due to a reduction in number and size of kernels in the heads of grain; and second, the production of small, shrunken kernels of inferior quality. Losses in yield and grain quality due to rust are difficult to estimate. It generally has been assumed that yield is inversely proportional to the degree of rust infection, but few experimental data regarding the actual effect of rust on yield are available. No detailed study of the effect of rust infection on the quality of grain has been published.

In previous studies on the relation between rust and the yield of cereal crops the method employed has been to correlate rust percentage with yield in a heterogeneous group of varieties and strains. Goulden and Elders (*10*), Hayes, Aamodt, and Stevenson (*15*), and Immer and Stevenson (*16*), found the degree of stem rust and leaf rust infection to be negatively correlated with the yield of cereal crops. The results were quite definite for the material studied but with other and entirely distinct groups of cereal varieties the values of the correlation coefficients obtained might have been quite different. This point was emphasized by Goulden and Elders (*10*) in a discussion of a heterogeneous group of varieties as a purely random sample.

Goulden and Greaney (*11*) reported the results of studies on the relation between stem rust and the yield of wheat in which varying amounts of rust infection in a single standard variety were correlated with yield. They obtained very satisfactory results, and found this method of considerable value in estimating the actual loss caused by stem rust of wheat at Winnipeg, Manitoba, in 1929.

The present paper gives the results of further studies on the effect of stem rust (*Puccinia graminis* Pers.) on grain quality and yield of both wheat and oats, and presents a method which has been used to increase precision in the estimation of annual losses from cereal rusts during the eight years 1925 to 1932, in Manitoba and Saskatchewan.

EXPERIMENTS ON THE PREVENTION OF CEREAL RUSTS BY SULPHUR DUSTING

During the past eight years, field experiments were made each season at Winnipeg, Manitoba, to determine the effectiveness of sulphur-dusting for the control of cereal rusts. In each year of the investigation a small field of summer-fallowed clay loam soil was chosen for the dusting experiments. The experimental field was planted to large blocks of Marquis wheat and Victory oats. An ordinary grain seeder was used. After the plants had appeared above ground the blocks were divided into small plots which varied in size in different years from 1/40th to 1/400th acre. The plots were rectangular in shape and suitable for harvesting and hand-dusting operations. Buffer strips and alleys were left at the ends and sides of adjacent plots to serve as protection against dust drift.

Each year during the five years, 1925 to 1929, the field experiments were made under conditions of natural rust infection. In 1930, 1931, and 1932, in order to insure a sufficient amount of rust, the grain was grown under conditions of an artificially-induced rust epidemic in conjunction with naturally occurring infection. The last three years' tests must therefore be considered as unusually severe.

In order to make the dusting tests as accurate as possible, the Latin Square plan of randomized experiment was used in which each dusting treatment occurred

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[2] *Plant Pathologist, Dominion Rust Research Laboratory, Winnipeg, Man., Canada.*

once, and once only, in each row and in each column. The amounts of rust on different replicates, and to some extent on individual plots in each replicate, were varied by applying sulphur dust to the growing plants at different rates and time-intervals. Dusting operations were commenced each year just as soon as rust appeared in the vicinity of the experimental plots. Thereafter, sulphur was applied at regular intervals until the grain was beginning to ripen. This method of obtaining all gradations of rust infection on a single standard variety was very suitable for the purpose of the present study. Methods of treating plots of grain with sulphur to obtain varying degrees of rust infection are given in Table 1.

TABLE 1.—*Sulphur dust treatments used in a 10 × 10 Latin Square in order to obtain varying degrees of rust infection.*

Treatment Number	1	2	3	4	5	6	7	8	9	10
Amount of sulphur per application per acre in lbs.	15				30			45		0
Interval between dust applications in days	15	10	5	2	10	5	2	10	5	0
Total number of dust applications	2	3	7	18	3	7	18	3	7	0

Final readings for leaf rust, based on the scale of stem rust percentages adopted by the Office of Cereal Crops and Diseases, United States Department of Agriculture, were made when the leaves were still green; those for stem rust, just before the plants ripened.

The grain in the outside drill rows, and along the ends of each plot, was removed by hand before harvest to minimize errors due to border effect. The yield results were then secured by harvesting and threshing each plot separately. Weight per measured bushel was ascertained by bulking the threshed grain of each replicated series of plots, and weighing according to Canadian Government Standards. The correct marketable grade of each treatment was determined by officials of the Western Grain Inspection Division, Winnipeg, Manitoba.

The results of eight years' field experiments have demonstrated the effectiveness of dusting with sulphur for the prevention of cereal rusts. Each year stem rust and leaf rust of both wheat and oats were completely controlled by relatively light, but frequent, applications of sulphur. The amount of rust infection was always directly associated with yield as indicated by weight per measured bushel and with grain quality. Furthermore, the degree of rust control was always directly proportional to the rate and frequency of sulphur dust application. Complete details of the sulphur dusting experiments and the results obtained have been given by Bailey and Greaney (*2*, *3*), and Greaney (*12*, *14*).

METHOD OF ESTIMATION

The method of estimating losses from cereal rusts used in this study may be given very briefly. The results of a 12 x 12 Latin Square experiment made in 1930 to determine the most suitable rate and frequency of sulphur dust application for the control of stem rust of wheat will be used. In the final analysis of the results of this experiment, rust percentages and yields of individual plots were correlated. In the Latin Square the degree of stem rust severity varied on different plots from 2 to 95%. The results from 144 plots in this experiment are given in the form of a regression graph in Figure 1. The correlation coefficient for stem rust and yield is −0.9379. The significance of the coefficient was tested by the method given by Fisher (*8*). This involves calculating—

$$t = \frac{r}{\sqrt{1 - r^2}} \cdot \sqrt{n^1 - 2} \quad ,$$

where n^1 is the number of pairs of values entering into the correlation. For the coefficient -0.9379, the value of t is 32.5, a very significant value, as for odds of 100:1 a t value of only 2.5 is required.

The straight line regression in Figure 1 indicates that the relation between amount of stem rust infection and yield is linear. To test the linearity of regression the analysis of variance method as developed by Fisher (*8*) was used. In this experiment the deviations from the regression straight line are not significant, and this indicates that an increase of 10% of rust from 10 to 20% reduced the yield the same amount as an increase of 10% of rust from 70 to 80%.

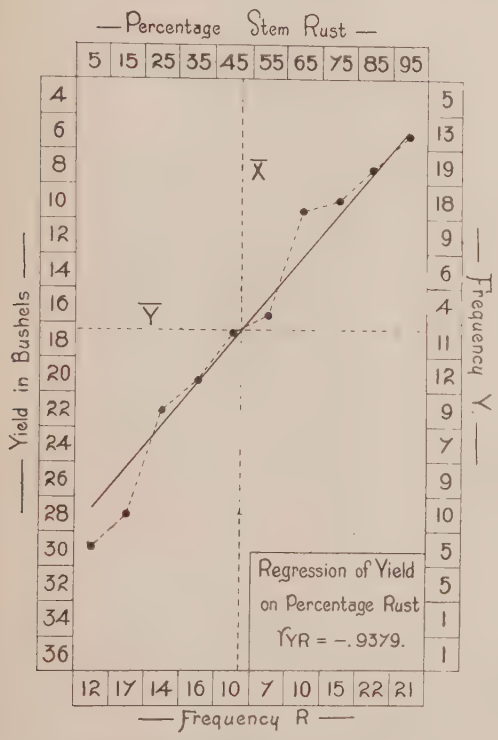

FIGURE 1. *Regression of yield on percentage stem rust in a 12 x 12 Latin Square wheat-dusting experiment in 1930.*

From these results it is evident that the determination of regression of yield on percentage rust gives a reliable value for the reduction in yield corresponding to a given increase in the amount of rust infection. In 1930 the reduction in yield of wheat, for each 10% of stem rust, was 2.5 bushels per acre (Table 3). Expressed in percentage of the average yield (30.4 bushels) of the highest yielding series of plots in the experiment, that is, the series of plots which received the most effective sulphur treatment, and which represents the average yield to be expected in the absence of stem rust, the reduction of 2.5 bushels for each 10% increase in the amount of rust infection represents 8.2% of the possible yield.

The results of this study demonstrate the actual effect of rust on yield in a single standard variety. It seemed possible that the results giving definite values for the reduction in yield corresponding to a given increase in the amount of rust might be used to obtain increased precision in the estimation of field losses from cereal rusts. Accordingly, the data accruing from field experiments made each season during the past eight years at Winnipeg, to determine the value of sulphur dusting for the control of cereal rusts, were used to calculate the annual losses due to stem rust in Manitoba and Saskatchewan.

Estimates of Losses in Yield

Each year, from 1925 to 1932, stem rust of wheat was almost completely controlled in plots which received the heaviest rate of sulphur at the greatest frequency of application. The results obtained during the period of the investigation, showing the annual yields in bushels obtained in the series of plots receiving the most effective sulphur treatment for rust control (practically rust-free), and the yield of plots which remained undusted (heavily rusted), are presented graphically in Figure 2. Figure 3 shows the actual annual loss in yield, due to rust, during the eight years 1925 to 1932. The results obtained at Winnipeg for the period 1928 to 1932, inclusive, showing yields of rust-free and rusted Victory oats, are presented graphically in Figures 4 and 5.

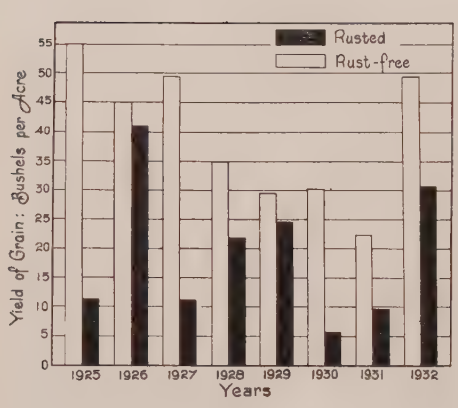

FIGURE 2. *Comparison of the annual yields of rust-free (dusted) and rusted (undusted) Marquis wheat during the eight years 1925-1932, at Winnipeg, Manitoba.*

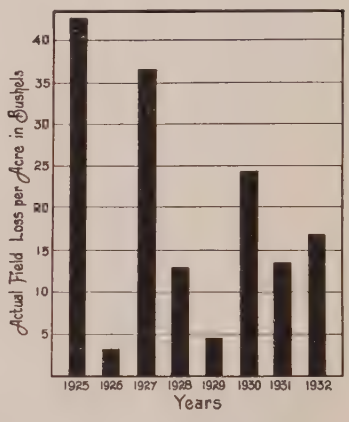

FIGURE 3. *Actual annual field losses from stem rust of wheat during the eight years 1925-1932, at Winnipeg, Manitoba.*

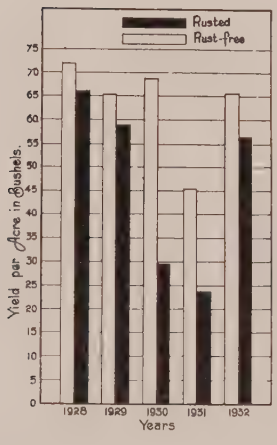

FIGURE 4. *Comparison of the annual yields of rust-free (dusted) and rusted (undusted) Victory oats during the five years 1928-1932, at Winnipeg, Manitoba.*

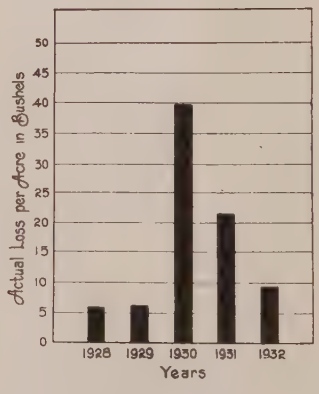

FIGURE 5. *Actual annual field losses per acre from stem rust of oats during the five years 1928-1932, at Winnipeg, Manitoba.*

Data from wheat and oat dusting experiments made during the period 1925 to 1932, inclusive, were analyzed statistically. Correlation coefficients for stem rust and yield in these experiments and the computed values of t are given in Table 2. The results in Table 2 show the relative seasonal severity and importance of stem rust epidemics during the past eight years at Winnipeg. Owing to the mild epidemic of stem rust in 1926, the relation between rust and yield could not be determined for that year.

TABLE 2.—*Correlation coefficients for stem rust in relation to yield of wheat and oats.*

Crop	Year	Correlation coefficient	t	1% point
Wheat	1925	−0.9711	37.7	3.1
	1927	−0.9474	13.6	2.8
	1928	−0.1731	0.9	2.9
	1929	−0.4143	5.2	2.6
	1930	−0.9379	32.5	2.5
	1931	−0.8037	12.2	2.8
	1932	−0.5341	6.1	2.7
Oats	1930	−0.8860	17.5	2.8
	1931	−0.6520	6.7	2.7
	1932	−0.4949	4.9	2.8

In these experiments the regression of yield on percentage rust was linear. In testing the linearity of regression, it was found that the deviations from the regression straight line were not significant. This indicated that a uniform increase in the amount of rust resulted in a uniform reduction in yield.

The calculated reductions in yield of Marquis wheat in per cent, for each 10% of stem rust, are given in Table 3, and losses in yield of Victory oats for each 10% severity of rust, are given in Table 4. These results, giving actual values for the reduction in yield for each 10% increase of rust, were used in estimating the annual field loss from stem rust in Manitoba and Saskatchewan.

In estimating losses in yield of cereal crops from values representing the percentage-loss in yield for a given amount of disease infection, it is extremely important to obtain accurate disease infection data. For the purpose of estimating annual

TABLE 3.—*Actual yields of rusted and rust-free Marquis wheat at Winnipeg, Man., during the period 1925 to 1932, inclusive, and the calculated reduction in yield for each 10% of stem rust.*

Year	Yield per acre in bushels		Per cent stem rust severity at Winnipeg	Reduction in yield for each 10% of stem rust	
	Rust-free (dusted)	Rusted (undusted)		Bushels per acre	Per cent of possible yield
1925	55.0	12.5	85	5.3	9.7
1926	45.0	42.0	15	—	—
1927	48.8	12.2	85	3.6	7.4
1928	35.0	22.0	48	—	—
1929	29.0	24.5	30	2.0	6.9
1930	30.4	6.1	90	2.5	8.2
1931	22.8	9.4	76	1.8	7.9
1932	48.2	31.2	70	1.5	3.1
Eight-year average	39.3	20.0	63	2.1	5.4

TABLE 4.—*Actual yields of rusted and rust-free Victory Oats at Winnipeg, Man., in 1930, 1931 and 1932, and the calculated reduction in yield for each 10% of stem rust.*

Year	Yield per acre in bushels		Per cent stem rust severity at Winnipeg	Reduction in yield for each 10% of stem rust	
	Rust-free (dusted)	Rusted (undusted)		Bushels per acre	Per cent of possible yield
1930	74.8	29.5	70	4.7	7.0
1931	45.3	23.8	65	2.6	5.8
1932	65.6	56.4	56	1.5	2.3
Three-year average	61.9	36.6	64	2.9	5.0

field losses from stem rust the average amount of rust infection for any given district was obtained from the annual plant disease surveys (*6*), Dominion Experimental Farms Reports (*7*), and the rust survey reports of the Dominion Rust Research Laboratory, Winnipeg. Acreage, yield, and price statistics used in this study were obtained from the Provincial Departments of Agriculture of Manitoba and Saskatchewan.

For the purpose of estimation Manitoba was divided into two areas. Climatic and soil conditions prevailing in Area I (Red River Valley of Manitoba) closely approximated the conditions under which the dusting experiments were made. Furthermore, a large proportion of the wheat grown in this area was Marquis. The second area (Area II) comprised all grain-growing districts in Manitoba other than the Red River Valley. Soil and climatic conditions, as well as varieties grown in this area, differed considerably from the conditions at Winnipeg. Total wheat production figures for Saskatchewan were used for the purpose of estimation. In calculating oat rust losses, the total production figures for Manitoba and Saskatchewan were used.

More accurate estimates would have been possible for Area II of Manitoba and for the province of Saskatchewan if more exact data concerning varieties grown had been available. Due to differences in soil, climate, cultural practices, varieties grown, etc., which exist throughout Manitoba and Saskatchewan, estimates based on the yielding ability of rusted and rust-free standard varieties are not as accurate as they might be desired. Nevertheless, certain errors in the method of estimation are offset by others. The results presented here are considered reliable and conservative, and have the merit of being based on experimental methods.

The wheat production figures of Manitoba for 1930, and the value for reduction in yield corresponding to each 10% increase in the amount of stem rust infection, may be used to demonstrate the method of estimating field losses from rust. The average per cent severity of stem rust infection in Area I of Manitoba, in 1930, was 65%. In that year Area I produced 22,492,000 bushels of common wheat (Table 5). In 1930, each 10% of stem rust reduced the yield of Marquis wheat grown at Winnipeg, 8.2% (Table 3), so that the total percentage-loss in Area I was 53%. According to this method of estimation, if rust had not been present in 1930, the wheat crop of Area I would have yielded 48,163,000 bushels. This represents a loss in yield of wheat due to stem rust, of 25,671,000 bushels.

In 1930 the average severity of stem rust in Area II of Manitoba was only 40%. The total loss from rust in this area was 32.8% of a possible yield of 33,908,000 bushels, or 11,122,000 bushels (Table 5). The average price of wheat, at point of shipment in Manitoba in 1930, was 51 cents per bushel. Based on acreage, yield, and price statistics, the monetary loss for the whole of Manitoba in that year reached the sum of $18,764,000.

TABLE 5.—*Estimated annual losses of wheat in Manitoba during the eight years 1925-1932, due to stem rust, calculated by comparing yields of rusted and rust-free Marquis wheat grown at Winnipeg, Manitoba.*

Year	Area*	Actual production of rusted crop in bushels (000)	Average per cent stem rust severity	Calculated production of rust-free crop in bushels (000)	Loss in yield due to rust		Rust loss in dollars (000)
					Bushels (000)	Per cent of possible yield	
1925	I	14,740	70	45,919	31,179	67.9	36,791
	II	24,714	50	47,988	23,274	48.5	27,463
1926	I	18,017	10	19,045	1,028	5.4	1,121
	II	33,660	5	34,594	934	2.7	1,018
1927	I	8,250	65	15,896	7,646	48.1	8,104
	II	22,523	45	33,768	11,245	33.3	11,919
1928	I	18,192	30	21,709	3,517	16.2	3,235
	II	34,191	15	37,205	3,014	8.1	2,773
1929	I	12,309	30	15,522	3,213	20.7	3,823
	II	19,256	10	20,683	1,427	6.9	1,698
1930	I	22,492	65	48,163	25,671	53.3	13,092
	II	22,786	40	33,908	11,122	32.8	5,672
1931	I	14,614	35	20,185	5,571	27.6	2,284
	II	12,386	20	14,710	2,324	15.8	953
1932	I	21,054	20	22,446	1,392	6.2	487
	II	25,868	10	26,696	828	3.1	290
Eight-year average for Manitoba					16,673	24.7	15,090

* I—*Common wheat grown in Red River Valley, Manitoba.*
II—*All other wheat grown in Manitoba.*

TABLE 6.—*Estimated yield losses of oats in Manitoba in 1930, 1931 and 1932, due to stem rust, calculated by comparing yields of rusted and rust-free Victory oats grown at Winnipeg, Manitoba.*

Year	Area*	Actual production of rusted crop in bushels (000)	Average per cent stem rust severity	Calculated production of rust-free crop in bushels (000)	Loss in yield due to rust		Rust loss in dollars (000)
					Bushels (000)	Per cent of possible yield	
1930	I	13,577	55	22,076	8,499	38.5	1,785
	II	36,985	45	53,993	17,008	31.5	3,572
1931	I	9,088	40	11,833	2,745	23.2	522
	II	16,412	30	19,869	3,457	17.4	657
1932	I	11,706	25	12,414	708	5.7	92
	II	30,882	15	31,969	1,087	3.4	141
Three-year average for Manitoba					11,168	19.9	2,256

* I—*Oats grown in Red River Valley, Manitoba.*
II—*All other oats grown in Manitoba.*

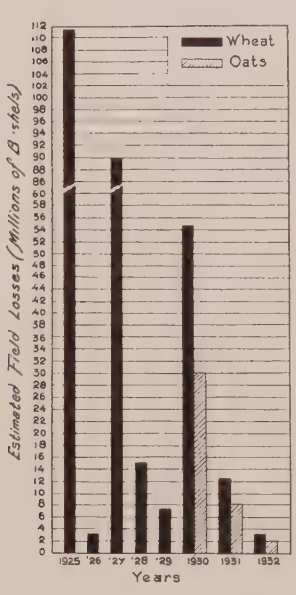

FIGURE 6. *Estimated annual losses in yield from stem rust of wheat and oats in Manitoba and Saskatchewan from 1925 to 1932, inclusive.*

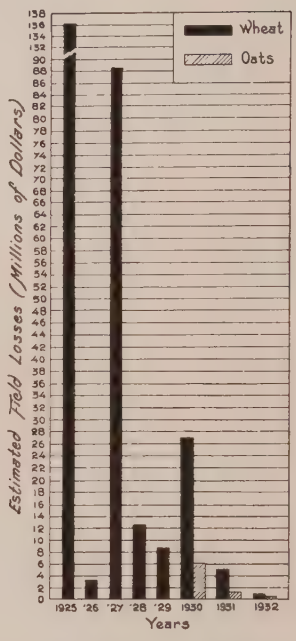

FIGURE 7. *Estimated annual losses in dollars from stem rust of wheat and oats in Manitoba and Saskatchewan from 1925 to 1932, inclusive.*

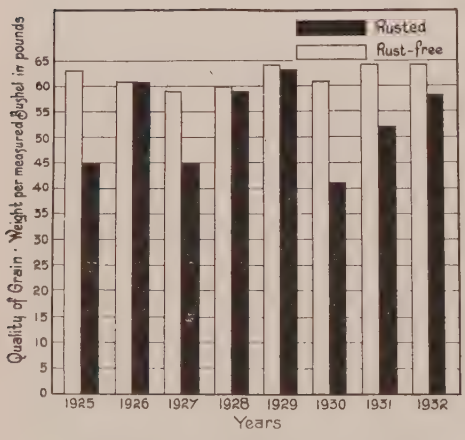

FIGURE 8. *Comparison of the weight per measured bushel (quality) of rust-free (dusted) and rusted (undusted) Marquis wheat during the eight years 1925-1932, at Winnipeg, Manitoba.*

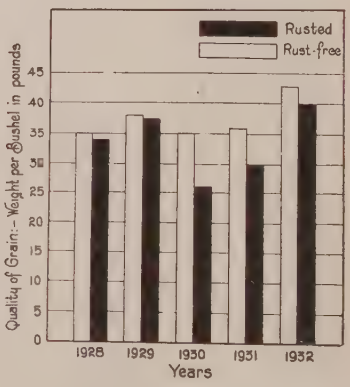

FIGURE 9. *Comparison of the weight per measured bushel (quality) of rust-free (dusted) and rusted (undusted) Victory oats during the five years 1928-1932, at Winnipeg, Manitoba.*

TABLE 7.—*Estimated annual losses of wheat in Saskatchewan during the eight years 1925-1932, due to stem rust, calculated by comparing yields of rusted and rust-free Marquis wheat grown at Winnipeg, Manitoba.*

Year	Actual production of rusted crop in bushels (000)	Average per cent stem rust severity	Calculated production of rust-free crop in bushels (000)	Loss in yield due to rust		Rust loss in dollars (000)
				Bushels (000)	Per cent of possible yield	
1925	239,062	20	296,602	57,540	19.4	71,925
1926	216,963	1	218,140	1,177	0.5	1,271
1927	249,494	30	320,686	71,192	22.2	69,056
1928	307,693	5	316,231	8,538	2.7	6,574
1929	154,314	3	157,463	3,149	2.0	3,243
1930	202,730	10	220,838	18,108	8.2	8,510
1931	119,480	5	124,328	4,848	3.9	1,842
1932	197,403	2	198,634	1,231	0.6	369
Eight-year average for Saskatchewan				20,723	7.4	20,348

TABLE 8.—*Estimated annual losses of oats in Saskatchewan in 1930, 1931 and 1932 due to stem rust, calculated by comparing yields of rusted and rust-free Victory oats grown at Winnipeg, Manitoba.*

Year	Actual production of rusted crop in bushels (000)	Average per cent stem rust severity	Calculated production of rust-free crop in bushels (000)	Loss in yield due to rust		Rust loss in dollars (000)
				Bushels (000)	Per cent of possible yield	
1930	125,509	5	130,061	4,552	3.5	682
1931	67,700	5	69,721	2,021	2.9	363
1932	108,200	2	108,700	500	0.5	60
Three-year average for Saskatchewan				2,357	2.3	368

Estimates of annual losses from stem rust of wheat and oats in Manitoba and Saskatchewan during the period 1925 to 1932, inclusive, are given in Tables 5, 6, 7, and 8, and presented graphically in Figures 6 and 7.

The average annual loss in yield to wheat from rust, in Manitoba and Saskatchewan, during the last eight years, was 15.5%. This represents a loss of 37,396,000 bushels valued at $35,438,000. The average annual loss of oats in Manitoba and Saskatchewan for 1930, 1931, and 1932 was 11.1%, or 13,525,000 bushels, representing a financial loss of $2,624,000. Rust does not do so much damage in Alberta as in the provinces of Manitoba and Saskatchewan, and an estimate of the losses has not been computed for that province. From the estimates presented in this paper it would seem that the total loss from leaf and stem rusts of wheat and oats, even at moderate grain prices, amounts to $40,000,000 annually in the three prairie provinces.

ESTIMATE OF LOSSES IN GRAIN QUALITY

The presence of a large proportion of small shrunken kernels is reflected directly on the weight per measured bushel of grain, and seriously reduces its market value. Little experimental data regarding the effect of rust on the quality of

cereal crops are available. The data presented here indicate how seriously rust injures the quality of the grain, and give a measure of the loss which occurred at Winnipeg during the period 1925 to 1932.

The results of sulphur dusting experiments made during the last eight years at Winnipeg, showing the weight per measured bushel of heavily rusted (undusted) and practically rust-free (heavily dusted) Marquis wheat, are presented graphically in Figure 8. The effect stem rust had on weight per bushel of Victory oats, in the five years 1928 to 1932, is shown in Figure 9.

A statistical study of the data accruing from wheat dusting experiments conducted in 1925, 1927, 1930, 1931, and 1932, was made to determine the effect of stem rust on the quality of Marquis wheat. In the final analysis of the results of each experiment rust percentages and weights per bushel of grain grown in individual plots were correlated. The results from 144 plots in the 1930 experiment are given in the form of a regression graph in Figure 10. The correlation coefficient for stem rust and weight per measured bushel is -0.7331, a very significant negative coefficient.

Correlation coefficients and regression equations were calculated also for the relation between stem rust and weight per bushel in 1925, 1927, 1931, and 1932. These are given together with their t values in Table 9. To test the significance of the linearity of regression, the analysis of variance method was used. In every case the regression of weight per bushel on percentage rust was linear, indicating that a uniform increase in rust resulted in a uniform reduction in weight per measured bushel.

TABLE 9.—*Correlation coefficients for percentage stem rust infection and weight per measured bushel (quality) of Marquis wheat.*

Year	Correlation coefficient	t	1% point
1925	−0.9273	7.4	3.1
1927	−0.9284	10.9	2.8
1930	−0.7331	12.8	2.6
1931	−0.8949	18.2	2.7
1932	−0.8424	18.3	2.6

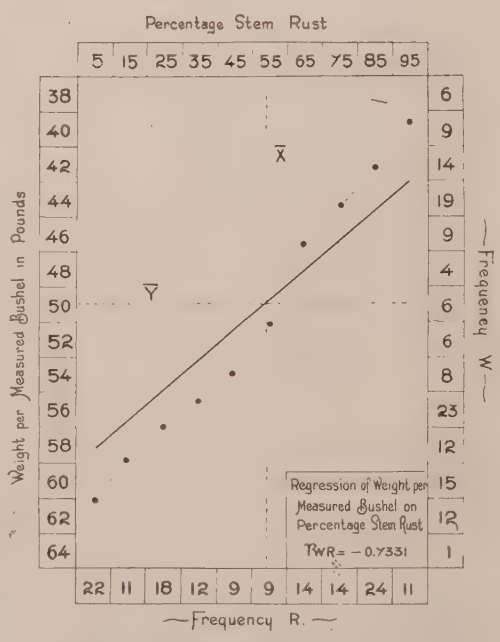
Percentage Stem Rust
5 15 25 35 45 55 65 75 85 95
38 40 42 44 46 48 50 52 54 56 58 60 62 64
Weight per Measured Bushel in Pounds
6 9 14 19 9 4 6 6 8 23 12 15 12 1
—Frequency W.—
Regression of Weight per Measured Bushel on Percentage Stem Rust
TWR = −0.7331
22 11 18 12 9 9 14 14 24 11
—Frequency R.—

FIGURE 10. *Regression of weight per bushel on percentage stem rust in a 12 × 12 Latin Square wheat-dusting experiment in 1930.*

Table 10 gives the values in pounds, and in per cent, of the possible weight per bushel for the reduction in weight of grain corresponding to each 10% increase in the amount of stem rust. These values are based on results obtained from the series of plots in each experiment which received the heaviest sulphur treatment. Rust was almost completely prevented and the highest quality of grain was produced in plots so dusted.

The results in Table 10 show the effect rust has on the quality of small grain crops, and offer convincing evidence that inferior quality of grain induced by rust is a very important factor in cereal crop production. This preliminary study suggests a method of estimating losses in grain quality due to rust. If reliable

TABLE 10.—*Weight per measured bushel of rusted and rust-free Marquis wheat grown during the period 1925 to 1932, inclusive, at Winnipeg, Man., and the calculated reduction in weight per bushel (quality) for each 10% of stem rust severity.*

Year	Weight per bushel Pounds		Per cent stem rust severity at Winnipeg	Reduction in weight per bushel for each 10% of stem rust	
	Rust-free (dusted)	Rusted (undusted)		Pounds	Per cent of possible weight per bushel
1925	63	46	85	2.4	3.8
1927	58	45	85	1.5	2.6
1930	61	41	90	1.9	3.1
1931	64	51	76	1.8	2.8
1932	64	59	70	0.9	1.4

field data concerning weight per measured bushel of grain for given districts were available, the percentage-loss values, as given in Table 10, could be used to increase precision in the estimation of annual losses in quality from rust. Owing to the difficulty of securing reliable field data, no field estimates of losses in grain quality in Western Canada have been made. More information concerning losses in grain quality, due to cereal rusts, would be of considerable value in estimating yields for crop reports.

DISCUSSION

Previous studies (*13*, *14*) have demonstrated the effectiveness of sulphur dust in preventing the development of leaf rust, and some of the minor leaf and stem diseases of cereals. Leaf rust of wheat caused considerable damage in Manitoba and Saskatchewan in 1925, 1927, and 1932, but it was not an important factor in other years. In 1930 oats in the experimental plots at Winnipeg were heavily infected with crown rust. Fortunately, during the course of the investigation, there was no marked development of leaf and stem diseases of wheat and oats, other than rust. It must be assumed that slight reductions in yield and grain quality were caused each year by leaf rusts, and some of the minor diseases of wheat and oats. The results of the dusting experiments show clearly, however, that losses suffered at Winnipeg during the period of the present study, were due mainly to the presence of stem rust.

In a recent study Flor, Gaines, and Smith (*9*) found that percentage of stinking smut was inversely correlated with yield of wheat, and that wheat varieties respond differently to bunt infection under different conditions. In an estimation of rust losses in North Dakota, in 1927, Waldron (*17*) compared the yielding ability of resistant and susceptible varieties of wheat which possessed similar yielding capacities in absence of rust. He found that wheat varieties responded quite differently to rust infection when grown in different regions. Recent studies in Manitoba have confirmed the results of these workers.

In view of the difference in varietal response to disease infection, physiologic forms, and to environmental conditions, it is difficult to secure an exact measure of the loss in yield and grain quality from stem rust. Cereal varieties are known to respond differently to rust infection, and the results obtained with one variety, as used in the present study, cannot be promiscuously applied to all varieties, or even to the same variety when it is grown under different environmental conditions. Although it generally has been assumed that yield is inversely proportional to percentage of rust infection, little accurate experimental data are available on this point. The data presented here show that yield and grain quality are negatively

associated with stem rust, and that uniform increases in the amount of stem rust infection result in uniform reductions in yield and quality of grain of both wheat and oats.

The method of employing percentage-loss values, obtained from the results of experiments in which disease infection and yield in one variety are correlated, must be used judiciously in estimating field losses from plant diseases. While this method of estimation is subject to certain obvious sources of errors, it has the merit of being based on the results of controlled experiments. The method is considered valuable in that it can be used to increase precision in the estimation of field losses from cereal diseases.

Summary

During the past eight years field experiments have been made each season at Winnipeg, Manitoba, to determine the value of sulphur dusting for the control of cereal rusts. The data accruing from experiments, in which the amounts of rust on individual plots were varied by sulphur dustings at different rates and time intervals, were used to estimate the loss in yield and grain quality due to stem rust (*Puccinia graminis* Pers.).

The method employed in this study has been to correlate rust and yield, and rust and weight per measured bushel of grain, in a single standard variety. Each year, during the course of the study, the results were summarized in the form of correlation coefficients and regression equations. When the correlation coefficients obtained were statistically significant, it was found that the regression of yield, and of weight per bushel, on percentage stem rust, was linear, indicating that uniform increases in rust result in uniform reductions in yield and grain quality.

From the results of each dusting experiment it was possible to determine the reduction in yield, and weight per bushel of grain, corresponding to a given increase in the percentage of rust. Percentage-loss values, giving the reduction in yield and in grain quality for each 10% increase of rust, were determined. The values so obtained were used in calculating the annual losses, due to stem rust, in Manitoba and Saskatchewan. The method has been used also to estimate losses in yield and grain quality due to leaf rusts, and to some of the other diseases of cereal crops.

From data on wheat dusting experiments made in 1925, 1927, 1930, 1931, and 1932, it was found that stem rust was significantly associated with grain quality as indicated by weight per measured bushel.

Estimates based on acreage, yield, and price statistics indicate an average annual loss in yield to wheat in Manitoba and Saskatchewan during the eight years 1925 to 1932, of 15.5%. This represents an annual loss of 37,396,000 bushels valued at $35,438,000. The average annual loss of oats in Manitoba and Saskatchewan in 1930, 1931, and 1932 was 11.1% or 13,525,000 bushels, estimated to be worth $2,624,000.

The results of this study indicate that even in the so-called non-rust years, rust caused quite a substantial loss. Losses in yield and grain quality from rusts of wheat and oats, even at moderate grain prices, amount to at least $40,000,000 annually in the three prairie provinces of Canada.

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FIELD EXPERIMENTS ON THE PREVENTION OF CEREAL RUSTS BY SULPHUR DUSTING (1930-1932)[1]

F. J. Greaney[2]

Cereal rusts cause enormous losses to small grain crops in most of the grain-growing areas of the world. During the present century destructive epidemics of rust have occurred with persistent regularity in the spring-wheat region of Canada and the United States. In most years, black stem rust *Puccinia graminis* Pers., is a very important factor in cereal crop production in Western Canada.

Kightlinger (*4*), in 1924, demonstrated the possibility of controlling cereal rusts by dusting growing plants with sulphur. In 1925 Bailey and Greaney (*1*) in Manitoba, Lambert and Stakman (*6*) in Minnesota, and Kightlinger and Whetzel (*5*) in New York, obtained very effective control of rusts on cereals with sulphur dust. An investigation to determine the practical possibility of preventing loss from cereal rusts by the use of fungicidal dusts has been carried on during the eight years, 1925 to 1932, at the Dominion Rust Research Laboratory, Winnipeg, Manitoba. The results of dusting experiments in Manitoba from 1925 to 1929, inclusive, have been reported by Bailey and Greaney (*1*, *2*), and Greaney (*3*). This paper presents the results of field experiments made in 1930, 1931 and 1932, and is a further contribution to our knowledge concerning the prevention of cereal rust by the use of dust fungicides.

The rates of sulphur dust used in these experiments were 45, 30, and 15 pounds per acre at each application. The time-intervals tested were 20, 15, 10, and 2 days. In each experiment initial dust applications were made when rust was first found in the district, but not necessarily in the experimental plots. Thereafter, the plants were dusted at regular intervals until the grain was beginning to ripen. Kolodust, a finely-divided sulphur dust, was used throughout the tests. The length of the dusting period varied in different years from 30 to 38 days.

The results obtained in 1930, 1931 and 1932, demonstrated the effectiveness of sulphur dusting for the control of cereal rusts. In these years leaf rust and

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stem rust of both wheat and oats were almost completely controlled by dusting, even in the presence of severe epidemics. From the experimental data it was possible to make a very accurate estimation of the annual loss in yield and grain quality, caused by rust under field conditions.

In 1930, a bad rust year, the yield of Marquis wheat was increased 24.3 bushels, or approximately 400% by dusting. Furthermore, eight 30-pound dustings raised the quality of grain from "Feed" weighing 40 pounds per bushel, to "1 Northern", weighing 60 pounds per bushel. Yield was increased over 135% in 1931. By preventing leaf and stem rust in 1932 dusting increased the yield of Marquis wheat 63%.

Crown rust and stem rust of oats were effectively prevented when frequent applications of sulphur dust were made. The increase in yield of Victory oats in 1930, due to rust control, was 45.3 bushels per acre, and the weight per measured bushel of grain was improved from 26 to 35 pounds. In 1931 the yield was increased almost 100% by dusting, while an increase in yield of 15% resulted in 1932.

During the course of this investigation it was observed that frequent applications of sulphur dust to growing wheat plants markedly prevented the development of scab, black chaff, smudge, and some of the minor leaf- and stem-spotting diseases of wheat. As in previous studies it was found that, although large amounts of sulphur were applied to the soil, no marked fertilizer effect occurred.

The results of experiments to determine the most effective and economical dust fungicide indicated that finely-divided sulphur dusts were the best for rust control. Of the dusts tested Kolodust, a finely-divided sulphur dust, gave the most satisfactory results. Medium grades of sulphur dust, although they did not afford the plants as much protection as did some of the finer and more expensive dusts, were very effective fungicides in 1931 and 1932. The results demonstrated that pure sulphur dust of 300-mesh fineness is an effective fungicide against rusts of cereals.

The effect of sulphur on the amount of rust infection, and on the consequent grain quality and yield of both wheat and oats, was least with light, infrequent dust applications, and greatest with heavy, frequent ones. In Manitoba, where the dusting period is usually from four to five weeks, there was definite evidence to show that under ordinary field conditions relatively light sulphur dust applications (30 pounds per acre), at fairly close intervals (5 days), will insure effective and economic control of stem rust of both wheat and oats, and reduce, by a very significant degree, the amount of leaf rust and crown rust. In general it was found that the interval between applications was a much more important factor in determining the effectiveness of sulphur dust treatments than was rate of application. The results have shown that early initial dust applications prevent the accumulation of viable inoculum on the plants and thus make the subsequent control of rust relatively easy.

It is difficult to formulate sulphur dusting schedules for rust control which would be applicable in all seasons and in all regions. To a very large extent the rate and frequency of dusting will have to be decided each year and as the season advances, according to the weather conditions, the progress of the rust, the condition of plant growth, and by the degree of control achieved by previous dust applications.

At present the sulphur dusting method is recommended for the use of experimentalists, seed growers, and grain exhibitors in the grain-growing regions of Canada. Whether or not dusting for the control of cereal rusts can be made a profitable agricultural practice will depend largely on such economic factors as, relative grain prices, cost of production, cost of dust fungicides and dusting equipment. The practical possibilities of dusting would be enhanced if more intensive cultural practices were employed. On the other hand, the general introduction of commercially desirable rust-resistant varieties would remove the necessity of providing protection from cereal rusts.

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A PRELIMINARY STUDY OF THE REACTIONS TO STEM RUST OF CERTAIN WHEAT VARIETIES IN DIFFERENT STAGES OF DEVELOPMENT[1]

W. Popp[2]

Certain varieties of wheat are known to be susceptible in the seedling stage to some physiologic forms of stem rust (*Puccinia graminis tritici* (Pers.) Erikss. and Henn.), but, in the adult stage, to possess a high degree of resistance (approaching immunity in the field) to all forms of stem rust so far found in Canada. This fact led the writer to undertake a preliminary study of the reactions of these varieties to stem rust to ascertain at what stage in the development of the plants this change from susceptibility to high resistance occurs, and if the high resistance of the adult plants could be correlated with any morphological change in the plants as they passed through successive stages of development.

Historical Review

Hayes and Aamodt (*7*) found that, in a cross between Marquis and Kota, the seedling reaction of families to physiologic forms 19 and 27 could not be used to determine which families would be resistant to several forms in the field. Hayes, Stakman and Aamodt (*8*) pointed out that "seedling plants, apparently susceptible in the greenhouse, are sometimes rather highly resistant in the field". Aamodt (*1*) stated that some wheat varieties, including H-44-24, are susceptible in the seedling stage to certain forms of stem rust but in the field are highly resistant to these forms. Goulden, Neatby and Welsh (*3*) showed that the high resistance of H-44-24 in the adult stage is independent of the seedling reaction. Goulden, Newton and Brown (*4*) compared the seedling and the adult plant reactions of fourteen varieties of wheat to sixteen physiologic forms of stem rust, and found that, in H-44-24, Hope, Acme, Pentad, and Black Persian, those physiologic forms which produce large pustules on seedlings produce smaller pustules and a smaller percentage of infection on adult plants; while, in such varieties as Garnet, Marquis, and Quality, a close agreement exists between the seedling and the adult plant reactions.

Hursh (*9*) produced evidence to show that the ratio of sclerenchyma to collenchyma in culms of resistant varieties, such as Kota and Acme, is much greater than in susceptible varieties, such as Marquis and Little Club. He concluded that varieties with a large amount of sclerenchyma are less likely to be injured by rust than varieties with a small amount of sclerenchyma, as the sclerenchyma in the former acts as a mechanical barrier to the spread of the rust mycelium, while in the latter the spread of the mycelium is not thus limited.

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Hart (*6*), in a study of the amount and distribution of sclerenchymatous tissue in different wheat varieties and in different parts of the same variety, found that seedlings possess no morphological resistance; and that mature plants possess relatively little morphological resistance in the base of the leaf sheath, in the leaf blade, or in the upper portion of the peduncle, but a very decided amount in the lower portion of the peduncle and in the flattened side of each joint of the rachis. In the middle portion of the peduncle, in the leaf sheath, and in various parts of the head of mature plants, she found that there may be a certain degree of morphological resistance, but that the effectiveness of such resistance differs greatly in different wheat varieties.

Gassner (*2*) concluded from field experiments that, in general, seedling plants of wheat varieties were more resistant to stem rust than were the same plants in later stages of development.

Materials and Methods

In order to have plants in different stages of development available for inoculation, two plans of seeding were followed. In the first one, seed of the varieties H-44-24, Acme, and Marquis, were sown in pots in the greenhouse at intervals of one week, so that the plants arising from the first sowing were in head when those from the last sowing were in the first leaf stage and those from the intermediate sowings were in intermediate stages. The leaves and culms of all the plants were inoculated on the same date with form 21 of *Puccinia graminis tritici*, a form to which the three varieties are susceptible in the seedling stage. After the usual period of incubation, the plants were placed in the same section of the greenhouse so that the temperature and light intensity would be the same for all the plants.

In the second plan of seeding, seed of H-44-24, Hope, H-44-24 x Marquis R.L. 450, H-44-24 x Marquis R.L. 204, Marquis, Quality, and Reward, was sown on the same date. When the plants were in the first-leaf stage, two pots of each variety were inoculated with form 15 of *P. graminis tritici*. None of these varieties in the seedling stage is resistant to this form. Each succeeding week, until the plants had ceased to grow, two more pots of each variety were inoculated. As the inoculations were made at different times, the environmental conditions during the developmental period of the pustules varied somewhat, although the amount of variation was not very great.

It might be mentioned that in no case was the same plant inoculated twice, so that only one reading was made of the rust reaction of any individual leaf. As the plants of each variety were of different ages when inoculated, some of the first (second, or third, etc.) leaves developed pustules when young, others when old, and others at intermediate ages. The reactions of a leaf (first, second, or third, etc.) at different ages were therefore obtained from a given leaf on a number of different plants.

As soon as the uredinia arising from each inoculation had attained their maximum development, the infection type (or types) and the number of infections on each of the several plant parts were recorded and were used as an index of the resistance or susceptibility of each part at that particular stage of development. Most attention was paid to the reaction of the leaves, as these parts are easily distinguishable and the unfolding of each leaf marks, as it were, a step forward in the development of the plant.

In order to ascertain to what extent, if any, the presence of sclerenchymatous tissue in the leaves and stems might be responsible for resistance in adult plants of some wheat varieties, sections were made of the leaves and peduncles of plants of H-44-24, Acme, Marquis, Reward and Quality. The first two varieties possess mature plant resistance, the last three do not.

The inclusion in this paper of the various data collected in this study would occupy an undue amount of space. The results will, therefore, be presented in summary form.

Physiological Study

Leaves.—In H-44-24, the first three leaves to develop on a plant are moderately susceptible to forms 15 and 21. Shortly before these leaves begin to become chlorotic, their infection type indicates that they are slightly less susceptible, although the number of infections on them are not appreciably less than on younger leaves. The tips of the fourth and subsequently-formed leaves, as they emerge, and the remaining portions of these leaves, just as they unfold, are only slightly less susceptible than the first, second, and third leaves. Before, however, either the fourth, or any later-formed leaf has fully expanded, its tip, and later its remaining parts, become resistant. Shortly after each of these leaves has attained complete expansion, resistance is evident throughout the entire leaf. At time of full expansion, the fifth leaf shows greater resistance than the fourth. The sixth leaf after full expansion is very highly resistant. When the plant reaches the shot-blade stage, the fourth, fifth and sixth leaves are practically immune.

The reactions of Hope and H-44-24 x Marquis R.L. 450 to form 15 conform closely to the reactions of H-44-24, as just indicated. The reactions of the different leaves of Acme to form 21 correspond more or less with the leaf reactions of H-44-24 to this form. The first three leaves of Acme are somewhat more susceptible than those of H-44-24; and resistance in the fourth, fifth, and sixth leaves, when these are fully expanded, is less pronounced than in corresponding leaves of H-44-24. A marked increase of resistance occurs in the seventh, as compared with the sixth, leaf of Acme. After Acme plants are in head, they are highly resistant.

No appreciable difference is evident either in the reactions of the different leaves of Marquis plants to forms 15 and 21, or in any particular leaf before and after it is fully expanded. The average infection type of all leaves indicate high susceptibility, although there is a tendency for leaves, shortly before they begin to wither, to show slight resistance.

The reactions of Quality, Reward and H-44-24 x Marquis R.L. 204 are very similar to those of Marquis.

Leaf Sheaths.—Observations were made only on the reactions of the sheaths of the fourth and subsequently-formed leaves. Newly-appearing portions of the leaf sheaths of H-44-24, as well as of Hope and H-44-24 x Marquis R.L. 450, are susceptible, but soon become resistant. This change from susceptibility to resistance usually takes place in approximately two days.

Unexposed portions of the sheaths remain longer susceptible than exposed portions. In a normal leaf sheath, one edge overlaps the other. At the shot-blade stage, the head causes the two edges of the sheath enveloping it to be drawn apart so that the portion which was previously covered becomes exposed. After the head emerges from the sheath, the two edges of the sheath resume their original position, one edge overlapping the other. Plants of H-44-24 inoculated while the sheaths were thus distended produced, after these portions had returned to their unexposed positions, heavy infections on portions temporarily exposed. The remaining portions of the sheaths developed only a few infections of a highly resistant type.

The leaf-sheaths of Marquis, Reward, Quality, and H-44-24 x Marquis R.L. 204, like their leaves, are highly susceptible until they begin to lose their green colour, at which time they are slightly less susceptible.

Peduncles.—The behaviour of the peduncles of H-44-24 plants, with respect to susceptibility and resistance, is very similar to that of the leaf sheaths. After the head has emerged from the sheath and while the peduncle continues to elongate, each successive newly-exposed portion of the peduncle is susceptible to forms 15 and 21, while each portion, after being exposed for about two days, becomes highly resistant. On removing the leaf sheath from the peduncle just after the latter had ceased to elongate and immediately inoculating the whole length of the peduncle, it was found that the lower part of the peduncle is quite susceptible whereas the upper part (that above the sheath) is highly resistant.

The peduncles of Hope and H-44-24 x Marquis R.L. 450 react similarly. Those of Marquis, Reward, Quality, and H-44-24 × Marquis R.L. 204 remain susceptible until the plants begin to lose their green colour.

It may be mentioned in passing that the awns and glumes, as they emerge from the sheath, are very susceptible in all the varieties mentioned.

Morphological Study

A morphological study was made of the leaves and peduncles of H-44-24 and Acme, varieties which after heading are highly resistant in the field to all physiologic forms but susceptible to some forms in the seedling stage; and of Marquis, Reward, and Quality, varieties which remain susceptible to many forms until the plants begin to ripen. Sections were made of the first leaf and of each succeeding leaf; also of the peduncles.

The mycelium of the stem rust fungus develops in collenchymatous tissue, and is unable to penetrate sclerenchymatous tissue. The fungus, therefore, can spread from one chlorophyllous strand of tissue to another if its course is not barred completely by intervening sclerenchymatous tissue.

In the present investigation, it was found that the first leaf of H-44-24 plants, and the first and second leaves of Marquis seedlings possessed no sclerenchymatous girders, or stereomes, so that in these leaves no appreciable mechanical obstruction to the spread of the rust mycelium is present. In the second leaf of H-44-24 and in the third leaf of Marquis, stereomes connecting the sheaths of some of the larger bundles to the upper epidermis begin to appear. Each succeeding leaf, in both varieties, showed a progressive increase in the number of stereomes connecting bundle-sheaths to the upper and the lower epidermis. In the topmost leaf of a plant of either variety, stereomes were more numerous than in any of the earlier-formed leaves. The proportion of sclerenchymatous to collenchymatous tissue in each leaf of an H-44-24 plant, from the second to the topmost one, is greater than the proportion in corresponding leaves of Marquis. That is, in the upper leaves of Marquis, as compared with corresponding leaves of H-44-24, there is a greater amount of collenchymatous tissue in which the fungus can spread. The total cross-sectional area of the collenchymatous strands in the topmost leaf of Marquis was approximately two and one half times that in the topmost leaf of H-44-24. In Acme the proportion of collenchymatous to sclerenchymatous tissue in the leaves is somewhat greater than in H-44-24, the proportion in Reward and Quality, slightly greater than in Marquis.

A difference in the proportion of collenchymatous to sclerenchymatous tissue in the peduncles of H-44-24, Acme, and Marquis, was also found. The proportion in Acme is less than in H-44-24, but in both these varieties the proportion is very considerably less than in Marquis. In Reward and Quality, the proportion is approximately the same as in Marquis.

There is, therefore, at first sight, an apparent correlation between the amount of collenchymatous tissue in wheat plants and their degree of susceptibility. H-44-24 and Acme possess a relatively smaller amount of such tissue than do Marquis, Reward, and Quality and they are very highly rust resistant in the adult stage, whereas Marquis, Reward, and Quality are generally very susceptible.

It is beyond doubt that the sclerenchymatous tissue limits to some extent the spread of rust mycelium in such varieties as H-44-24, Hope, and Acme, but resistance in these varieties cannot be solely attributed to the mechanical obstruction offered by the sclerenchymatous tissue. In the present investigation, it was found that, if in resistant parts of an adult plant of H-44-24, the mycelium of a pustule spread the full width of the collenchymatous strand in which it was growing, it was limited in its longitudinal spread by necrotic collenchymatous cells. Frequently, however, the mycelium of a pustule in resistant tissue did not spread to the full width of the collenchymatous strand in which it was growing, but was hemmed in on all sides by

necrotic collenchymatous cells. This indicates that the plants possess definite physiologic resistance.

Furthermore it was observed that in the upper portion of the peduncle the vascular bundles tend to fuse with one another, so that there are fewer bundles and consequently less obstruction offered by the sclerenchymatous tissue to the spread of rust mycelium in this region than in the lower portion of the peduncle. This observation is in agreement with Hart (*6*) who found that the upper portion of the peduncle possesses relatively little morphological resistance. The present investigation has shown, however, that the upper portion of the peduncle of some varieties may be very highly resistant while, at the same time, the lower portion may be quite susceptible. Moreover, in culms of Marquis, the collenchymatous strands just below the nodes are smaller than those in the upper part of the peduncles of H-44-24, yet the H-44-24 peduncles are ordinarily resistant while the culms of Marquis are susceptible. It would, therefore, appear that, in varieties such as H-44-24, Hope, and Acme, the rôle which the sclerenchymatous tissue plays in conferring resistance upon a plant is only of minor importance in comparison with the physiological resistance which the various parts develop with advance in age.

Summary

A preliminary study was made of the reactions at different stages of development of H-44-24, Acme, and Marquis to form 21, and of H-44-24, Hope, H-44-24 x Marquis R.L. 450, Marquis, Reward, Quality and H-44-24 x Marquis R.L. 204 to form 15 of *Puccinia graminis tritici;* also a study of the internal morphology of the leaves, leaf sheaths and peduncles.

The first three leaves to develop on a plant of any of these varieties are susceptible to the physiologic form used. In later stages of development, newly-appearing tissue of the leaves, leaf sheaths, and peduncles of H-44-24, Hope, Acme, and H-44-24 x Marquis R.L. 450 is susceptible for about two days but afterwards becomes resistant. In these varieties, the fourth leaf when fully expanded is resistant, and, at full expansion, each succeeding leaf is more resistant than the preceding one. Resistance increases in these leaves with age, for by heading time the fourth and all subsequently-formed leaves are practically immune. The leaves, leaf sheaths, and peduncles of Marquis, Reward, Quality, and H-44-24 x Marquis R.L. 204 remain susceptible until the different parts begin to lose their green colour.

Temporarily-exposed portions of the leaf-sheaths of H-24-44 plants are susceptible when the regularly-exposed portions are highly resistant.

The proportion of sclerenchymatous to collenchymatous tissue in each leaf, from the second to the topmost one, of H-44-24, Acme, Marquis, Reward and Quality increases with each successive leaf, the proportion being greater in the leaves of H-44-24 than in corresponding leaves of Acme, and in Acme greater than in the other varieties. In the peduncles, the proportion was greater in Acme than in H-44-24, but greater in H-44-24 than in the rest.

The sclerenchymatous tissue limits to some extent the spread of rust mycelium in such varieties as H-44-24, Hope, and Acme, but resistance in these varieties cannot be solely attributed to the mechanical obstruction offered by the sclerenchymatous tissue.

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EXPERIMENTS ON THE CONTROL OF LOOSE SMUT OF WHEAT BY SEED TREATMENT[1]

W. F. Hanna and W. Popp[2]

Loose smut has not been regarded as a serious disease of wheat in Western Canada. A few plants affected with loose smut can be found in most commercial fields of hard red spring wheat, but the loss from this disease has been so light that most farmers have not considered it worth while adopting special control measures. During the past few years, however, an appreciable amount of loose smut has been found on Reward wheat, a new hard red spring variety of high quality. In 1930, counts of loose smut were made in 15 fields of Reward in different districts of Manitoba, and the average infection was 2.2%. In one of these fields 7.6% of the heads were infected.

The modified hot water treatment is the only seed treatment which has given satisfactory control of loose smut of wheat. Occasionally, in order to get perfect control with certain varieties of wheat, it has been considered necessary to make slight changes in the time or temperature of treatment. Thus, Hurst (*1*) found that Huron wheat required treatment for 20 minutes at 54° C. (129.2° F.) to eliminate the loose smut.

In response to frequent requests for information on methods of controlling loose smut in Reward wheat, experiments were made to determine the effectiveness of the modified hot water treatment in controlling loose smut in this variety. Particular attention was given to the effect of the treatment on seed germination. Some preliminary trials have been made also with other methods of seed treatment.

I. Germination of Hot-Water-Treated Wheat

Germination tests of the hot-water-treated wheat were made with Reward seed supplied by the Superintendent of the Dominion Experimental Station, Morden, Man. This wheat was grown in 1929, and was machine threshed. The kernels were plump, fairly uniform and of good general appearance. Lots of 100 seeds, apparently free of injury, were counted out and placed in small cheese-cloth bags. This seed was soaked in tap-water at room temperature for 4 hours, dipped for one minute in water at 120° F., and then immersed for 10 minutes in the treating bath. Temperatures ranging from 125° to 135° F. were employed. Eight lots of 100 seeds were treated at each temperature.

Four lots of the seed treated at each temperature were dried in the laboratory until the kernels appeared to be of normal moisture content; the other four lots were spread out on a table for about an hour to allow the surface moisture to evaporate. Two lots of the dried and two lots of the moist seed were then dusted with Deloro copper carbonate, and placed to germinate in pots of soil in the greenhouse. The remaining four lots of dried and moist seed were similarly placed to germinate

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TABLE 1.—*The effect of the hot water treatment on the germination of Reward wheat.*

Treatment	Per cent emergence			
	Seed dried		Seed undried	
	Without copper carbonate	With copper carbonate	Without copper carbonate	With copper carbonate
(Unsterilized soil)				
Untreated	88	90	—	—
4 hrs. pre-soak	94	95	95	94
4 hrs. pre-soak; 1 min. 120° F.; 10 min. 125° F.	94	93	93	97
4 hrs. pre-soak; 1 min. 120° F.; 10 min- 126° F.	88	94	91	97
4 hrs. pre-soak; 1 min. 120° F.; 10 min. 127° F.	92	93	91	93
4 hrs. pre-soak; 1 min. 120° F.; 10 min. 128° F.	82	88	85	95
4 hrs. pre-soak; 1 min. 120° F.; 10 min. 129° F.	76	79	73	91
4 hrs. pre-soak; 1 min. 120° F.; 10 min. 130° F.	67	79	59	92
4 hrs. pre-soak; 1 min. 120° F.; 10 min. 131° F.	59	62	63	80
4 hrs. pre-soak; 1 min. 120° F.; 10 min. 132° F.	45	53	34	68
4 hrs. pre-soak; 1 min. 120° F.; 10 min. 133° F.	35	49	34	67
4 hrs. pre-soak; 1 min. 120° F.; 10 min. 134° F.	21	24	21	46
4 hrs. pre-soak; 1 min. 120° F.; 10 min. 135° F.	10	18	11	30
(Sterilized soil)				
4 hrs. pre-soak; 1 min. 120° F.; 10 min. 129° F.	—	—	92	93

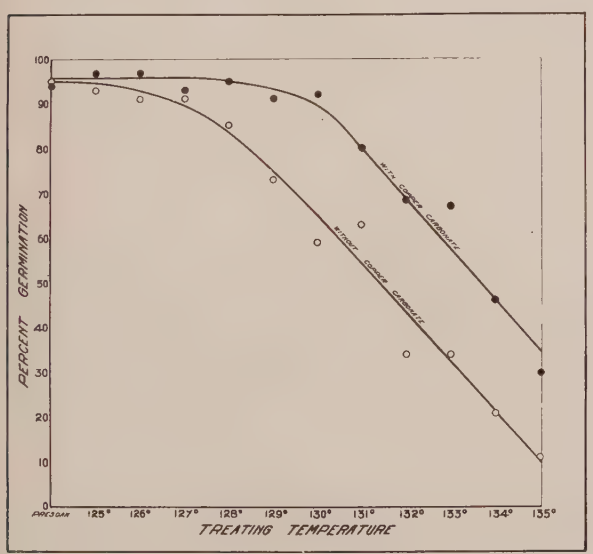

FIGURE 1. *The effect of the hot water treatment on the germination of Reward wheat.*

in pots of soil, but without any dust treatment. The copper carbonate dust was applied to the treated seed to determine the maximum degree of germination. Other seed treated at 129° F. was germinated in steam-sterilized soil. Two of these lots were dusted with copper carbonate while the grain was still swollen, and then seeded; the other two lots were seeded without the preliminary dusting.

Counts of the number of seedlings produced by each lot of treated grain were made 14 days from the date of seeding. The mean per cent emergence of the different lots of seed has been summarized in Table 1, and presented graphically in Figure 1.

The results show that, when Reward wheat is immersed for 10 minutes in water at 129° F., few if any of the seeds are actually killed. About 15% of the treated seed has its power of germination impaired, but if it is protected against the attacks of soil organisms, either by dusting it with copper carbonate or by seeding it in sterile soil, a normal stand of seedlings can be obtained. Serious seed injury appears to begin above 130° F.

II. Control of Loose Smut of Reward Wheat by the Hot Water Treatment

The Reward wheat used in testing the effectiveness of the hot water method of treatment was kindly furnished by Mr. Wm. Pierce, Superintendent of the Provincial Experimental Farm, Birtle, Man. Duplicate 30 gm. lots of seed, each containing about 800 kernels, were weighed out for each treatment. The seed was then soaked in tap-water for 4 hours, dipped in water at 120° F., and transferred to the treating bath, where it was kept for 10 minutes. The treating temperatures were the same as those listed in Table 1 for the germination tests, *i.e.*, eleven different temperatures separated by one degree intervals from 125° to 135° F.

After treatment each lot of treated seed was sown in the field in a 15-foot row and, when the plants had headed out, counts were made of the number of smutty heads in each row.

The pair of rows sown with untreated seed produced a total of 33 smutty heads, whereas not a single infected head was found in any of the rows sown with treated seed. It is evident, therefore, that loose smut may be eliminated from Reward wheat by pre-soaking the seed for 4 hours and then immersing it for 10 minutes in water at a temperature of 125° F. or higher.

Some difficulty was experienced in applying the results of these laboratory experiments to farming practice. This difficulty arose mainly through the lack of suitable equipment for treating relatively large quantities of wheat. Under laboratory conditions small lots of grain can be brought rapidly to the required temperature. But when half-bushel sacks of wheat are immersed in the treating bath, some time may elapse before the grain in the centre of the sack has reached the required temperature, even though the temperature of the surrounding water is suitably regulated. This uneven heating of the grain may result in imperfect smut control. One method of overcoming the difficulty experienced in treating large quantities of grain would be to increase both the time and temperature of treatment. Some inexpensive and efficient apparatus for treating wheat with hot water would greatly simplify the problem of loose smut control.

III. Experiments With Simpler Methods of Loose Smut Control

The ideal seed treatment is one which farmers can easily and effectively apply with simple and relatively inexpensive apparatus. The hot water treatment for loose smut has not fully met these requirements, and most farmers hesitate to attempt temperature control with the equipment at their disposal. Efforts have been made, therefore, to obtain control of loose smut of wheat by simpler methods.

Hot Air Treatments.—Loose smut in naturally infected Reward wheat could not be controlled by heating the dry seed in an electric oven. Seed which had been dried for 30 minutes at 212° F., was reduced in germination from 88 to 29%, but a 60 gm. portion of it, when sown in two 15-foot rows, still produced 11 smutty heads.

As a substitute for the hot water treatment, it has been suggested that loose smut might be controlled by pre-soaking the seed in the usual way and drying it at a constant temperature in hot air. If a method of this kind were to prove effective the grain drying machinery installed in elevators might be utilized for treating wheat infected with loose smut.

With this end in view, some experiments were made to determine the effect on loose smut control of drying pre-soaked wheat in an electric oven maintained at a constant temperature. Small lots of naturally infected Reward seed, each weighing 66.5 gm., were used in these experiments. One-half of these lots of seed were soaked in tap-water for 4 hours, and the other half for 8 hours. After soaking, each lot was placed in a petri dish and dried at a constant temperature in an electric oven. The following temperatures were used: 129°, 131°, 133°, 135°, 140°, and 150° F. The periods of drying ranged from 10 to 60 minutes. After drying, 200 kernels from each lot of treated seed were used for a germinaiton test; the remaining portion of each lot, approximately 60 gm., was sown in two 15-foot rows in the field. When the rows had headed out, the number of smutty heads in each row was counted.

Space does not permit of the tabulation of the results of these experiments. None of the treatments eliminated the loose smut. In the two rows grown from seed pre-soaked for 4 hours and dried for 60 minutes at 150° F. there were 4 smutty heads, while in the two rows grown from seed dried for the same time at this temperature following pre-soaking for 8 hours, there were 6 smutty heads. Seventeen

TABLE 2.—*The effect of seed treatments on Reward wheat naturally infected with loose smut*—(Field experiments).

Treatment	Per cent germination	Smutty heads in two rows	
		As counted	Maximum expected, due to reduction in germination
(1930)			
Untreated	88	33	33
24 hrs. in 5% acetone	93	24	35
24 hrs. in 5% sodium chloride	44	27	17
8 hrs. in 0.1% sodium hydroxide	90	38	34
24 hrs. in 0.2% sulphuric acid	33	12	12
24 hrs. in 0.1% sulphurous acid	95	23	36
48 hrs. in 0.3% Semesan	—	20	—
(1931)			
Untreated	96	19	19
24 hrs. in 8% ethyl alcohol	79	11	16
24 hrs. in 8% methyl alcohol	88	17	17
24 hrs. in 0.31% Formalin	62	8	12
24 hrs. in 5% sodium sulphite	29	6	6
8 hrs. in 1% sodium bisulphite	13	13	3
24 hrs. in 1% Chlorazene	31	9	6
24 hrs. in 2% potassium iodide	87	2	17
12 hrs. in 5% potassium iodide	84	1	17

smutty heads were found in the pair of untreated rows. The germination of the two lots of treated seed was 84 and 82% respectively, whereas 96% of the untreated seed germinated. These results indicate that, under the conditions of these experiments, the temperature required for controlling loose smut by hot air treatment is considerably higher than that recommended for the hot water treatment.

Chemical Treatments.—Efforts have been made to control loose smut of Reward wheat by soaking the seed at room temperature in aqueous solutions or mixtures of the following substances: ethyl alcohol, methyl alcohol, acetone, formalin, potassium iodide, sodium sulphite, sodium bisulphite, sodium chloride, sodium hydroxide, sulphuric acid, sulphurous acid, Semesan, and Chlorazene (para-toluene-sodium-sulphochloramide).

Some preliminary experiments were made to determine the concentrations and times of treatment which would not cause too great a reduction in seed germination. Treating periods varying from 2 to 48 hours were used. When information on this point had been obtained, lots of naturally infected Reward wheat, each weighing 66.5 gm., were treated with the solutions. After treatment, 200 kernels were removed from each lot for a germination test, and the remainder was seeded in two 15-foot rows in the field. Shortly after the plants were in flower, counts were made of the number of smutty heads in each pair of rows. A total of 119 different treatments were tested. The results of a few of these have been summarized in Table 2. These data will serve to illustrate the effect of the various substances on seed germination and smut control. In the last column of this table there is given the maximum number of smutty heads which might have been expected to occur in each pair of rows due to the effect of the treatment on seed germination.

TABLE 3.—*The effect of seed treatments on Reward and Ceres wheat artificially infected with loose smut.*—(Greenhouse experiments).

Treatment	No. of Seeds	Per cent germination	No. of plants	No. of smutty plants	Per cent smutty plants
(Reward)					
Untreated	100	98	66	58	88
24 hrs. in 1% aniline blue	100	99	79	69	87
24 hrs. in 1% nachtblau	100	98	71	60	85
24 hrs. in 0.40% rhodamine B	100	73	49	42	86
24 hrs. in 0.25% auramine O	100	12	0	0	0
24 hrs. in 0.20% auramine O	100	40	25	22	88
24 hrs. in 0.15% hexylresorcinol in 50% glycerine	100	76	74	64	87
4 hrs. pre-soak, and 10 min. in water at 129° F.	100	94	45	0	0
(Ceres)					
Untreated	100	99	97	75	77
24 hrs. in 2% potassium iodide	100	89	74	37	50

The only substance which appreciably reduced the incidence of loose smut was potassium iodide. This substance was tested further with hand-inoculated Ceres wheat. In other experiments, hand-inoculated seed of Reward wheat was treated by the hot water method, and with solutions of four organic dyes and hexylresorcinol.

The treated seed was then sown in the greenhouse. The results of all the treatments are given in Table 3.

With the exception of the hot water treatment, potassium iodide was the only substance which significantly reduced the amount of loose smut. The untreated Ceres wheat produced only 22 healthy plants, whereas that treated with potassium iodide produced 37 healthy plants. The results of these experiments seem to warrant further tests with this substance.

Summary

The efficacy of the hot water treatment in controlling loose smut in Reward wheat, and its effect on seed germination have been investigated. Treatment for 10 minutes at temperatures between 125° and 135° F. inclusive eliminated loose smut from small lots of pre-soaked seed. When half-bushel sacks of seed were treated in the same manner at 129°F. the control was not as effective. Uneven penetration of the hot water into the sacks of grain probably accounted for the latter result.

The germinability of hot-water-treated Reward wheat has been improved by dusting it with copper carbonate.

Heating naturally infected seed of Reward wheat in an electric oven at 212° F. for 30 minutes failed to eliminate loose smut. Drying of the pre-soaked seed for 60 minutes at 150°F. likewise gave imperfect control.

Efforts have been made to control loose smut by soaking seed of Reward or Ceres wheat at room temperature in aqueous solutions or mixtures of a number of substances. Solutions or mixtures of ethyl alcohol, methyl alcohol, acetone, formalin, sodium sulphite, sodium bisulphite, sodium chloride, sodium hydroxide, sulphuric acid, sulphurous acid, Semesan, Chlorazene, aniline blue, nachtblau, rhodamine B, auramine O, and hexylresorcinol were used in these tests, but none of them was found to be effective.

The percentage of loose smut in Reward and Ceres wheat has been considerably reduced by soaking the seed for 24 hours at room temperature in a 2% solution of potassium iodide.

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STUDIES ON THE TEMPERATURE AND HOST RELATIONS OF *USTILAGO BROMIVORA* (TUL.) FISCH. V. WALDH. CAUSING SMUT OF *AGROPYRON* SPECIES[1]

G. W. Padwick and A. W. Henry[2]

Introduction

The smut disease of slender wheat grass due to *Ustilago bromivora* (Tul.) Fisch. V. Waldh. has been found causing considerable damage in Alberta. The fungus is seed-borne, infection apparently occurring in a manner similar to that in bunt of wheat (*3*). However, since slender wheat grass is perennial in habit a stand once infected will probably remain so indefinitely. In an infected plant some or all of the caryopses are eventually displaced by smut sori, resulting in a loss of seed (Figure 1). Also grains from normal plants of an affected stand become contaminated and rendered undesirable for seed purposes. In addition, the feed value of the hay crop is no doubt rendered somewhat inferior, while general observation indicates that the vigour of infected plants is reduced.

[1] *Contribution from the Department of Field Crops, University of Alberta, Edmonton, Alta., with financial assistance from the National Research Council of Canada.*

[2] *Graduate Assistant and Associate Professor of Plant Pathology, respectively.*

Since the discovery of slender wheat grass smut in Saskatchewan in 1916, it has been found in both Manitoba and Alberta. Reports of the Dominion Division of Botany for the past ten years (*2*) have indicated a rather wide distribution of the disease in Saskatchewan and Alberta. As early as 1924 a field at Saskatoon was found to have a 10% infection. In Saskatchewan in 1925 *U. bromivora* was found affecting *Agropyron dasystachyum* and *A. tenerum*. Severe damage was caused to small plots of slender wheat grass at Edmonton and Claresholm (Alberta) in 1929. In 1931 the most severe infection recorded in Alberta took place at Strathmore, where 90% of the heads were smutted; at Vermilion, 50%; and at Lacombe 25% infection occurred. In the same year smut was reported (2) occasionally on wild plants of *A. tenerum* in widely separated parts of Alberta, and a similar smut was collected on wild plants of *Bromus ciliatus* in different parts of the province. It is thus apparent that this smut is of quite widespread distribution.

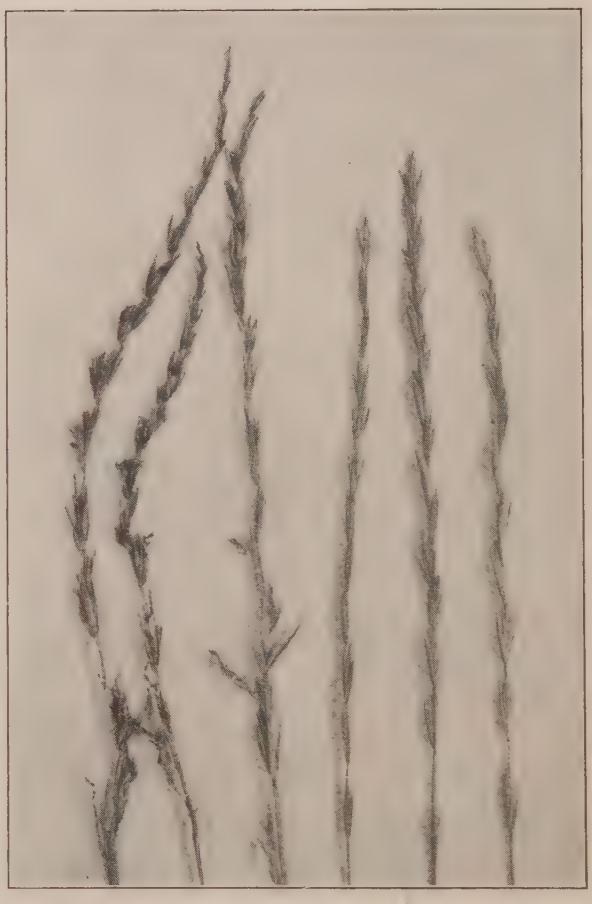

FIGURE 1. *Smutted and healthy heads of slender wheat grass.*

Influence of Seed Germination Temperature on Degree of Infection with Smut

It is well known that soil temperature at and immediately following the time of germination of seeds is an important factor influencing infection in a number of smut diseases. For example, Christensen (*1*) found that head smut of sorghum caused by *Sorosporium reilianum* was favoured by a rather high seed germination temperature, and that there was a quite well defined optimal temperature for infection, well within the limits of temperature, at which the sorghum seed will germinate. In cases where this occurs, it is conceivable that a certain amount of control of the disease might be effected by adjusting the date of seeding. With this possibility in mind, a special study was made of some temperature relations of *Ustilago bromivora*. As initial infection has been shown to take place in the seedling stage (*3*), infested seed was subjected to a range of temperature during the germination and early seedling stages. The effect of temperature on spore germination was also studied in order to correlate the results with infection data.

Seeds of *Agropyron tenerum* were dusted with spores of *Ustilago bromivora* (obtained from Strathmore the previous year) and seeded in pots on May 23rd, 1931. These pots were placed in chambers at temperatures ranging from 3° C. to 28° C., and were kept moist. The pots were removed to the greenhouse after periods

ranging from 6 to 14 days. The plants were kept in the greenhouse for approximately a month, and were then transplanted to the field.

The plants were examined in the fall after considerable numbers had headed out. A high degree of infection occurred throughout, regardless of the temperature of germination of the seed. The following year all the plants headed out, and infection counts were made early in July. The results of the counts for both years are found in Table 1.

TABLE 1.—*Effect of seed germination temperature on infection of Agropyron tenerum with Ustilago bromivora.*

Seed germination temperature °C.	Time kept at germination temperature days	First year		Second year	
		Number of of plants headed out	Percentage of smutted plants	Total number of plants	Percentage of smutted plants
3.1	11	5	100.0	45	97.8
9.5	12	21	71.4	44	90.9
15.5	11	24	81.7	36	94.4
22.3	8	24	81.7	57	86.0
25.0	6	25	80.0	43	83.7
28.0	6	13	84.6	49	98.0

The data indicate that the temperature of germination of smutty *Agropyron tenerum* seeds had no apparent effect on the degree of infection with smut. Furthermore, diseased plants which headed out during the first year were also smutted in the second year, suggesting that the fungus probably lives throughout the life of the plant.

In order to correlate the infection of plants with the germination of spores over a range of temperature, smut spores were dusted on distilled water in Syracuse dishes and placed at various temperatures. These spores were obtained from material similar to that used for inoculating the plants in the previous experiment, and were thus a year and a half old. Three dishes were used at each temperature. After a period of 24 hours large numbers of spores from each dish were examined and the germination recorded. The results of this experiment are found in Table 2.

TABLE 2.—*Effect of temperature on germination of spores of Ustilago bromivora, 18 months old.*

Germination temperature °C.	Number of spores counted	Percentage germination after 24 hours
8	203	12.8
10	192	20.3
15	211	25.6
19.5	218	8.7
25	253	15.0
29.5	348	2.0

The experiment was repeated, using spores produced in 1931, which were about six months old. A wider temperature range was used in this experiment, as indicated in Table 3.

It is seen from these results that the germination temperature range for *Ustilago bromivora* spores is very wide, which undoubtedly explains the fact that no appreciable differences in severity of infection were found when seeds of *Agropyron tenerum* dusted with smut spores were germinated at the different temperatures.

Apparently the optimum germination temperature for the spores lies between 10° C. and 15° C., but such a wide range would ensure infection of seedlings of *Agropyron tenerum* at all temperatures at which the seeds are likely to germinate under natural conditions, provided spores of the organism were present in any considerable quantity. The infection of plants placed at lower temperatures than those at which spores appear to germinate in distilled water, may be due to the fact that the seeds at the low temperatures showed no signs of germination until removed to the greenhouse, where probably a temperature was reached which was suitable for germination of both the grass seeds and the smut spores.

TABLE 3.—*Effect of temperature on germination of spores of Ustilago bromivora, 6 months old.*

Germination temperature °C.	Number of spores counted	Percentage germination after 24 hours
4	1000	0
8	781	2.7
10	700	11.1
15	1055	8.3
19.5	762	5.0
25	642	6.5
29.5	792	5.9
36.5	483	0

SUSCEPTIBILITY OF SPECIES OF *Agropyron* TO *Ustilago bromivora*

As mentioned previously, *U. bromivora* occurs naturally in western Canada on *Agropyron tenerum* and *A. dasystachyum*, as well as on *Bromus ciliatus*. Fraser and Scott (*3*) obtained infection of *Agropyron Richardsonii*, *A. dasystachyum*, *Bromus ciliatus* and *B. latiglumis* with smut from *A. tenerum*, but the percentage of smut was low as compared with that on *A. tenerum*. As other species of *Agropyron* are also important in western Canada, seeds of a number of species supplied by the Division of Forage Crops at the University of Alberta were artificially smutted and tested.

FIGURE 2. *Effect of temperature on spore germination of Ustilago bromivora.*

Inoculum was prepared from the same material as that used for temperature studies. Seeds of 14 species were dusted with smut spores, three of which, however, failed to head out during the summer and died during the winter. All were placed in flat boxes of soil early in May to germinate under temperature conditions varying from 12° C. to 18° C. After nine days they were removed to the greenhouse. They were transplanted to the field in the middle of June. Notes on infection were taken for the year of planting and for the following year, when all the surviving species headed out. Only the infection percentages for the second year are included in Table 4.

From these results it is evident that *Agropyron dasystachyum*, *A. Richardsonii* and *A. Griffithsii* are susceptible to *Ustilago bromivora* from *Agropyron tenerum*. No checks were used, but the possibility of infection being due to natural inoculum occurring on the seeds is practically ruled out by the fact that smut has not appeared in plants grown from the same lots of seeds for a number of years in the plots of the Forage Crop Division at the University. Of the other common species, the more important of which are perhaps *A. cristatum*, *A repens* and *A. Smithii*, it may be fairly safely concluded that they are either highly resistant or immune to the strain of *Ustilago bromivora* used in this inoculation study.

TABLE 4.—*Reaction of different species of Agropyron to Ustilago bromivora (second year).*

Species	Total number of plants	Smutted plants	Percentage of smutted plants
Agropyron cristatum	33	0	0
Agropyron dasystachyum	15	4	26.7
Agropyron desertorum	17	0	0
Agropyron glaucum	30	0	0
Agropyron Griffithsii	11	1	9.1
Agropyron obtusiusculum	5	0	0
Agropyron repens	45	0	0
Agropyron Richardsonii	28	4	14.3
Agropyron sibiricum	21	0	0
Agropyron Smithii	19	0	0
Agropyron tenerum	20	20	100.0

DISCUSSION

Western rye grass is a crop which may be seeded at almost any time during the spring or early summer in western Canada, provided sufficient moisture is present in the soil, during which time there is a considerable range of soil temperature. If infection with *Ustilago bromivora* could be avoided by seeding in soil at a temperature unsuitable for germination of the smut spores, control of the disease would no doubt be fairly simple. It is quite evident, however, that infection cannot be evaded in this way. Smut spores of this organism germinate successfully at a temperature lower than that at which it is practical to seed western rye grass. Indeed, experiments have shown that heavy infection occurs at the lowest temperature at which the seed will germinate. On the other hand, the spores will germinate and cause heavy infection at a temperature higher than that likely to obtain in our prairie soils for any length of time. It would appear that other methods must be adopted if this disease is to be controlled.

Infection of other species of *Agropyron* with the strain of *Ustilago bromivora* used in these experiments was low as compared with that of *A. tenerum*. We should, however, be mindful of the fact that smut from these other species might cause more severe infection on the same species. One cultivated species of increasing importance, namely *Agropyron cristatum*, appeared to be immune; it has not been found affected under natural conditions so far as can be ascertained. The evidence so far obtained is hardly sufficient to warrant the conclusion that other species of *Agropyron* are of much practical significance in the problem of slender wheat grass smut.

SUMMARY

1. Heavy infection of western rye grass with *Ustilago bromivora* occurred at all soil temperatures tested from 3° to 28° C. when infected seeds were germinated at these temperatures. There was no evident optimum temperature for infection indicated.

2. The spores of *Ustilago bromivora* germinated over a wide range of temperatures from 8° C. to 29.5° C. with an apparent optimum between 10° C. and 15° C.

3. Regulation of time of seeding appears not to be of value in the control of western rye grass smut.

4. The host range of *U. bromivora* has been extended to include *Agropyron Griffithsii*. *A. dasystachyum* and *A. Richardsonii* have previously been reported susceptible and were successfully infected but less heavily than *A. tenerum*. Seven other species of *Agropyron* tested including crested wheat grass, *A. cristatum* failed to produce smutted heads.

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MICROSCOPIC CHARACTERS OF THE "BLACK POINT" DISEASE OF WHEAT IN THE CENTRAL PROVINCES

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Pasinetti in a recent publication (*2*) has come to the conclusion that the "black point" or "punta nera" disease of San Martin Argentine wheat studied by him is entirely physiological, first because he did not find any organism in the discoloured tissues of the seed, secondly because the germination of the "black point" seed was as good as that of the healthy normal seed, and thirdly because from the blackened seeds healthy plants bearing normal ears and grains were developed. This conclusion of Pasinetti is of interest because first the symptoms described by him of the "punta nera" disease are very similar to the "black point" disease of wheat seed found in this Province; secondly if the "black point" affected seed is sown its germination is almost similar to that of the healthy seed; and thirdly, plants raised from the discoloured seeds develop normal ears and grains; but in spite of this similarity there is the important difference that in the discoloured tissues fungal hyphae have been found, and from diseased seeds, when planted on moist filter papers or culture media, are developed different kinds of fungi, like *Helminthosporium* sp., *Caldosporium* sp., *Ophiobolus* sp., *Fusarium* sp., *Alternaria* sp. and bacteria, even though these seeds may germinate in a majority of cases. These seeds if planted in fields or in pots would generally produce normal plants. However, there have been a few cases in which the seed has all the external characteristics of the "black point" disease, but whether it failed to germinate or germinated normally, in either case no organism was developed from it. It is possible the blackening of such a seed may be due to physiological causes as in the case of the "punta nera" disease of San Martin Argentine wheat, but from the external symptoms it is not possible to say which of the "black point" seed has or has not an organism in it, and what the organism is if it is present.

For the microscopic study of this disease either hand sections or microtomic sections--chiefly the latter—were examined. The seeds were fixed either in Schauddinn's Fluid or Chrome-acetic acid. The sections were stained with the lactophenol-cotton blue-saffranin method, as recommended by Lepik (*1*) or with Thionin and Orange G as recommended by Stoughton (*3*), but with the modification that the solution of Orange G was made in clove oil instead of in absolute alcohol as used by Stoughton. Lepik's method gave at first a very good differentiation between the parasite and the host, the blue stain of the hyphae being prominent against the red of the host tissues but the blue stain was not permanent; the hyphae soon lost their blue colour and so in old preparations it is with considerable difficulty the hyphae can be traced. The Thionin-Orange G method seems to be a better method

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than the lactophenol cotton blue-saffranin method, as the purple stain of the hyphae is permanent and they can be readily seen even under the low power. The hyphae are stained purple only when they are filled with protoplasm; the cells of hyphae which have lost their cell contents are stained yellow with Orange G.

FIGURE 1. *A section of the coleoptile showing the mycelium forming a sort of a stroma on the outside of the coleoptile. The hyphae in the inner tissues are intercellular, x 900.*

FIGURE 2. *A section of the coleoptile showing inter-cellular hyphae, x 900.*

The darkest part of the "black point" seed is the part of the furrow near the funicle. The blackening usually commences on the ventral side from this end. The hyphae are seen in great abundance in the funicle and in the pericarp in the central region of the furrow where the pericarp consists of several layers of thin-walled cells. The hyphae here are thin and chiefly inter-cellular, but occasionally intracellular as well; haustoria-like projections are found in the cells. A large number of hyphae seem to collect together in the cells which have broken cell-walls; this is to be seen particularly in the cells in the angles formed on either side of the vascular bundle. Whether the cell walls are ruptured by the hyphae or from some other cause it is impossible to say. These hyphae are thin and sparsely septate. In the pericarp on the dorsal side of the grain, on the side farther away from the furrow, the hyphae are both inter- and intracellular, more or less filling the cell cavity. Hyphae creep between the pericarp and the seed coat; in some places the mycelium is only one layer thick and in others many layers thick. The hyphae can be differentiated from the crushed cells of the inner epidermis of the pericarp by the purple staining of the cell contents of the hyphae; as the crushed cells take only the orange stain when stained with Thionin Blue and Orange G.

The hyphae in the cells of the pericarp next to the seed coat and the hyphae which lie between the pericarp and the seed coat form a sort of a stroma. The stromatic cells are short, broad and often globular. The inter-cellular hyphae are thin and not closely septate. Those in the outer layers of the pericarp are also thin and sparsely septate.

In the material examined hyphae have not been found in the inner parts of the embryo but they have been observed in the coleoptile (Figure 2) and also in the

first foliage leaf, though rarely. The hyphae in these parts are inter-cellular. The cells of the infected coleoptile and foliage leaf look as normal and turgid as those of the healthy seed.

At times the hyphae underneath the membranous pericarp covering the embryo collect together and form a sort of a stroma on the outer cells of the coleoptile (Figure 1).

Hyphae have not been observed in the aleuron layer or in the starch cells of the endosperm, but they are present in its empty crushed cells behind the scutellum. These hyphae are clearly seen as short lengths of purple colour when stained with Thionin Blue and Orange G., the crushed cells being stained orange yellow. Hyphae are also found in the tissues of the scutellum near the pericarp. They are inter-cellular, and the cells between which the hyphae lie cannot be differentiated from the cells of the scutellum where there are no hyphae.

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STUDIES ON THE PHYSIOLOGY OF THE OAT SMUTS[1]

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Abstract

Plants inoculated with a single monosporidial culture of *Ustilago avenae* or *U. levis* did not produce smutted heads.

Plants inoculated with two monosporidial cultures of opposite sex produced smutted heads. If the two cultures were of *U. avenae* most of the infected heads were "loose" in appearance and the spores in all of them were echinulate; if of *U. levis* most of the heads were "covered" in appearance and the spores in all of them were smooth; if one of the cultures was of *U. avenae* and the other of *U. levis*, the infected heads were usually of the "loose" type, and the spores in all of them were echinulate.

The sporidia of *U. avenae*, like those of *U. levis*, are of two kinds, (+) and (−); the sporidia of one species mate without difficulty with sexually opposite sporidia of the other species.

Hybrid spores derived from crosses between *U. avenae* and *U. levis* germinated readily and infected oat seedlings, but many of the sporidia produced by germinating hybrid spores, when removed from the promycelium and grown separately, failed to produce colonies.

A few monosporidial cultures have been obtained from F_1 chlamydospores resulting from the cross *U. avenae* x *U. levis*. These cultures, when back-crossed on the *U. avenae* parent produced echinulate chlamydospores; when back-crossed on the *U. levis* parent some produced echinulate spores and others smooth spores.

Monosporidial cultures from certain strains of *U. levis* produced colonies composed almost entirely of hyphae, whereas monosporidial cultures from other strains produced colonies of the sporidial type. When F_1 chlamydospores resulting from a cross between the two kinds of monosporidial cultures were germinated, segregation for these characters occurred.

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ON WOUND CORK IN ROOTS OF *MEDICAGO* AND *MELILOTUS*[1]

M. W. Cormack[2]

The root-rot diseases of *Medicago* (alfalfa) and *Melilotus* (sweet clover) are becoming increasingly important in Western Canada. Two fungi, namely, *Plenodomus meliloti* and *Sclerotinia* sp., are highly pathogenic to these crops, and, as shown by Sanford (*10*), the root rot caused by *P. meliloti* develops only during late winter and early spring, the progress of the disease being arrested when the temperature of the soil rises and good growth begins. Also, under our conditions, the damage from *Sclerotinia* sp. is more severe following the winter dormancy period than it is during summer. Observational evidence suggested that both root rots were influenced by the moisture content and the temperature of the soil, and that possibly the age, as well as the variety of the plants, were also important factors.

Artschwager (*1*), Artschwager and Starret (*2*), Conant (*5*), Weimer and Harter (*12*), and others have demonstrated the marked influence of certain environmental factors on the formation of wound cork in different plants. However, no information on the subject as it concerns alfalfa or sweet clover has been found in the literature. Consequently, it was decided to investigate the effect of these factors on the incidence of wound cork in roots of *Medicago* and *Melilotus*, and its importance in the development of the root rots indicated.

Material and Method

Preparation of plants for laboratory study.—Two varieties each of alfalfa and sweet clover were chosen on account of differences in hardiness. The seed was planted in the field late in June. Early in September, the requisite plants of each variety, uniform in size and vigour, were planted into deep wooden receptacles, taken into the laboratory, and grown under controlled conditions of soil temperature, and moisture.

When the plants were again growing vigorously, the soil was removed from one side of each tap root to a depth of 3 to 4 inches, and the surface of the root cleaned. With a sharp scalpel, a deep slit, extending to the central pith and about 20 mm. long, was then cut lengthwise in the tap root. Although tissue was not removed in making this slit, the incision tended to open, especially in growing roots. At one side of this incision, a shallow, tangential cut, about 1 mm. deep, was made. Immediately after the incisions were made, the soil was replaced as before. At 5-day intervals, representative plants were removed from each receptacle for histological study of the incidence and progress of wound cork beneath the incisions in the roots.

Regulation of soil temperature and soil moisture.—Soil temperatures at which the plants were held during the main experiment were 1°, 9°, and 18° C. The latter temperature was available under greenhouse conditions. For 1° and 9° C., and also the freezing test, which is described later, refrigerated rooms, thermostatically controlled and lighted by electricity, were employed. All soil temperatures were recorded by thermographs and proved to be very constant.

The soil moisture in one half of the containers, held at each temperature, was made up to somewhat above optimum, or about 70% moisture-holding capacity of the soil. The moisture content of the soil in the other half of the containers was rather low, being approximately 40% of its moisture-holding capacity. The two soil moistures were kept reasonably constant.

[1] *Contribution from the Division of Botany, Experimental Farms Branch, Department of Agriculture, Ottawa, Canada, co-operating with the University of Alberta. This paper constitutes one part of a thesis submitted April, 1931, to the University of Alberta, in partial fulfilment of the requirements for the degree of Master of Science.*

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Histological technique.—A portion of each freshly dug sample of roots was sectioned with a small hand microtome for preliminary examination, the remainder being preserved in form-acetic fixing solution. For later examination or for photographing, the fixed material was washed, embedded in paraffin, and cut into sections 10μ thick on a rotary microtome.

In staining, a modification of Bugnon's (*4*) technique, employing Sudan III and light green, was used. This stained cork cells bright orange and all other tissues green.

Arbitrary numerical values, from zero to ten, were used to express the extent of wound cork formation. These values were based on the width, uniformity and degree of suberization of the wound cork layers.

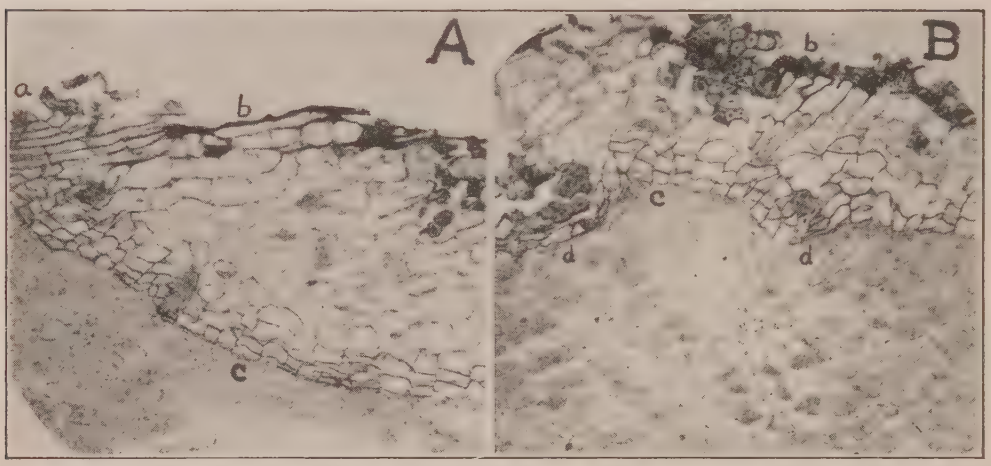

FIGURE 1. *Wound cork layers (c) beneath shallow tangential cuts (b) in alfalfa roots, 30 days after wounding. (× 85). A. Fusion of wound cork with external cork layer (a), at left. B. Fibre groups (d), causing interruption and deviation of wound cork. (× 85).*

EXPERIMENTAL RESULTS

General observations.—The healing of a wounded root was first indicated by the drying up of the ruptured cells just below the surface (Figure 1, A and B). This process was frequently followed by the deposit of a dark-staining substance. Wound cork was initiated by the formation of a meristematic phellogen layer beneath the injury. This consisted of a continuous layer of short, actively dividing cells, which soon laid down a layer of wound cork cells on the side next the wound. Under favourable conditions, this was followed by successive layers of wound cork. Normally, these cork cells became immediately suberized, as evidenced by their being stained a bright orange with Sudan III.

Wound cork layers were usually formed in a position parallel to the surface of the wound and were connected with the edges of the protective, external, suberized layer of the root (Figure 1, A). The depth in the tissues at which wound cork layers were formed varied greatly, but they were usually separated from the wounded surface by several layers of somewhat abnormal cells (Figure 1, A and B).

The histological studies of Jones (*6*), on frost injury in alfalfa roots were confirmed with regard to the varying potentialities of the different root tissues for wound cork formation. That is to say, wound cork formed most readily in the parenchymatous tissues directly below the external suberized layer, and in the phloem. It was often somewhat delayed in the vicinity of the cambium layer, and in the xylem. Fibre groups were incapable of wound cork formation, and they often interrupted the cork layers. Other cases were observed where the wound cork layer jutted out around the fibres (Figure 1, B, d).

The method of wounding the root apparently had some effect on the incidence of wound cork. It was generally formed most rapidly and uniformly beneath the shallow tangential cuts, but was frequently delayed and broken in the deep longitudinal slits.

Factors Influencing Wound Cork Formation in Roots of *Medicago* and *Melilotus*

SOIL TEMPERATURE

Laboratory studies on plants four months old.—In this experiment, the roots of two varieties each of alfalfa and sweet clover were operated upon and the plants were held as previously described at soil temperatures of 1°, 9° and 18° C. The amount of wound cork formed at different intervals after wounding is indicated by the values in Table 1.

At 1° C., no wound cork was formed during the course of the experiment, and there was no indication of subsequent development. At 9° C., wound cork began to form in 18 days, but in 28 days the layers were still only one cell wide and some-

Table 1.—*Effect of soil temperature and moisture on wound cork formation in roots of young Medicago and Melilotus plants.*

Variety	Soil Temperature Cent.	Soil Moisture	Wound cork rating* at different intervals after treatment				
			8 days	13 days	18 days	23 days	28 days
Grimm Alfalfa	1°	Dry	0	0	0	0	0
		Moist	0	0	0	0	0
	9°	Dry	0	0	0.9	2.4	3.4
		Moist	0	0	0	0.9	5.0
	18°	Dry	2.2	5.9	6.6	7.7	8.0
		Moist	0.6	4.2	6.6	6.8	7.2
Cossack Alfalfa	1°	Dry	0	0	0	0	0
		Moist	0	0	0	0	0
	9	Dry	0	0	0.9	2.0	2.4
		Moist	0	0	0.1	0.9	2.5
	18°	Dry	2.4	5.2	6.2	8.0	8.1
		Moist	1.0	4.7	7.0	7.4	7.8
White Blossom Sweet Clover	1°	Dry	0	0	0	0	0
		Moist	0	0	0	0	0
	9°	Dry	0	0	0.8	2.7	2.9
		Moist	0	0	0.3	1.7	3.5
	18°	Dry	2.9	4.5	5.9	7.5	8.3
		Moist	1.8	5.1	6.2	7.4	7.6
Arctic Sweet Clover	1°	Dry	0	0	0	0	0
		Moist	0	0	0	0	0
	9°	Dry	0	0	1.2	1.9	3.1
		Moist	0	0	0.4	0.6	1.7
	18°	Dry	4.8	5.8	7.9	8.1	8.5
		Moist	3.5	4.5	8.0	8.3	8.6

**Average numerical rating of four replicates.*

what broken. At 18° C., wound cork formed much more rapidly and a fairly continuous layer was present beneath wounds in 8 days. At this soil temperature, a very regular, well suberized cork layer, 2 to 3 cells wide, was observed beneath most wounds in 28 days.

Laboratory studies on overwintered plants nine months old.—In order to study the effect of overwintering on the development of wound cork, plants of two varieties each of alfalfa and sweet clover were removed from the field in March, stored at about 1° C., and immediately wounded. They were then planted in crocks containing soil of optimum moisture content, and held at soil temperatures of 3°, 8° and 16° C. for 28 days. The data obtained on wound cork formation are presented in Table 2.

TABLE 2.—*Effect of soil temperature on wound cork formation in roots of overwintered Medicago and Melilotus plants.*

Variety	Soil Temperature Cent.	Wound cork rating* at different intervals after treatment				Variety	Soil Temperature Cent	Wound cork rating* at different intervals after treatment			
		8 days	13 days	23 days	28 days			8 days	13 days	23 days	28 days
Grimm Alfalfa	3°	0	0	0	0	White Blossom Sweet Clover	3°	0	0	0	0
	8°	0	0	0.5	0.7		8°	0	0	0	1.1
	16°	0	3.7	3.0	5.8		16°	0	1.0	3.7	3.0
Cossack Alfalfa	3°	0	0	0	0	Arctic Sweet Clover	3°	0	0	0	0
	8°	0	0	1.0	0.7		8°	0	0	0	0.6
	16°	0	2.1	5.0	4.5		16°	0	2.3	4.0	4.7

**Average numerical rating of four replicates.*

Wound cork did not develop in the roots of any of the plants held at a soil temperature of 3° C. At 8° C., it was not present until 23 days after treatment, and only a partially formed layer was found beneath the wounds at the end of 28 days. At 16° C., a broken layer, 1 cell wide, was formed in 13 days; and after 28 days this had increased to a fairly regular layer 1 to 2 cells wide.

It will be noted that wound cork formation was considerably retarded in the roots of overwintered plants as compared to that in the roots of young plants which had not overwintered.

Field studies on young plants.—The field experiments were conducted during two months of contrasting temperatures, using vigorous plants of four varieties each of alfalfa and sweet clover. The first series of plants were wounded, as previously described early in September. During this month the mean soil temperature, based on daily averages as recorded by a soil thermograph, was fairly high, being 11° C. at a depth of 3 inches. A similar series of treatments were made early in October, which proved to be a month of relatively low temperatures. The mean soil temperature during this month, at the same depth, was 1.1° C., and no freezing was known to have occurred.

The results of these experiments confirmed very closely those obtained under laboratory conditions. Wound cork was first observed in the September series 10 days after treatment, and in 20 days a very uniform layer, 2 to 3 cells wide, was apparent beneath most incisions. However, under the low soil temperature conditions prevailing in October, no wound cork was formed in any of the wounded roots, and even at the end of 30 days there was no trace of phellogen development.

The results of both laboratory and field experiments indicate that wound cork in the roots of alfalfa and sweet clover is completely inhibited at a soil temperature of about 1° C., occurs very slowly about 9° C., and is accelerated above this temperature and up to 18° C., which was the highest soil temperature employed. These findings are in general agreement with those obtained by Priestley and Woffenden (*7*) Artschwager (*1*), and Weiss *et al* (*13*), with potato tubers; by Weimer and Harter (*12*) and Artschwager and Starrett (*2*), with sweet potato and gladiolus; and by Conant (*5*), with tobacco. These workers all report an acceleration of wound cork formation with a rise in temperature.

Soil Moisture

Although no reference was found in the literature concerning the influence of soil moisture on the development of wound cork, several investigators have reported a pronounced influence of atmospheric humidity in this respect. Artschwager (1), Priestley and Woffenden (*7*), and Weiss *et al* (*13*) state that a high relative humidity of the atmosphere had a decided acceleratory effect on wound cork formation in cut potato tubers. Weimer and Harter (*12*) report that a low atmospheric humidity inhibited wound cork formation in sweet potato tubers. On the other hand, Samuel (*8*) and Blackman and Matthaeii (*3*) found that dry air conditions favoured the formation of wound cork in the leaves of almonds and other trees.

As it was impracticable to attempt a study of the influence of soil moisture on wound cork formation under field conditions, this phase of the investigation was confined to the laboratory. The plants selected for treatment were grown in dry and moist soils, respectively, as previously indicated. Also, the usual surface tangential and deep longitudinal incisions were made in the roots. Representative results of these experiments are shown in Table 1.

Under the experimental conditions employed, the moisture content of the soil apparently did not have any marked influence. Wound cork was generally initiated slightly earlier in roots growing in the dry soil, but these early differences usually disappeared later.

Effect of Age, Condition and Variety of the Plant

Age.—Wound cork was studied in roots of alfalfa and sweet clover plants during their first year, and also during their second year of growth. Roots of vigorous plants, growing in the field during midsummer, were wounded and examined at intervals for wound cork. In sweet clover, suberization was greatly retarded in roots of the second summer's growth, as compared with that in roots of either young plants or overwintered plants in the early spring. Since sweet clover is a biennial, these results suggest that wound cork formation is retarded as the plants approach maturity. Wound cork appeared to form just as rapidly, however, in the roots of the second summer's growth of alfalfa as it did in roots of plants of the first season's growth. Weimer (*11*) concluded that the ability of alfalfa roots to heal injuries was greatest during their first year of growth.

Freezing.—It has already been shown in the soil temperature studies that wound cork formation proceeds more rapidly in roots of young, unfrozen plants than in roots of overwintered plants (Tables 1 and 2). These results were confirmed in studies on artificially frozen plants. In this experiment, the plants were gradually hardened off for a week then treated and held at a soil temperature of −5° C. for 3 days. After thawing, they were held at a greenhouse temperature of approximately 18° C. Under these conditions, the formation of wound cork in the frozen roots was considerably retarded, as compared to that in the roots of young, unfrozen plants, but not as much as it was retarded in the roots of naturally overwintered plants.

Vigour.—The vigour of the plant was found to influence the formation of wound cork. It was markedly retarded and sometimes even completely inhibited in the roots of weak plants, which were grown under rather unfavourable conditions

in the greenhouse. A comparison of the data obtained in the different experiments shows that wound cork formed most rapidly in the roots of plants kept under natural growing conditions in the field. It did not form, at any time, in roots of plants kept under non-growing conditions.

Variety.—Significant varietal differences in ability to form wound cork apparently did not occur in either alfalfa or sweet clover. Whatever differences occurred in this respect were not consistent (Tables 1 and 2). The high degree of natural variability, which was observed in different plants of the same variety, is a factor which probably explains some of the variable results obtained in this and other phases of the investigation.

Discussion

Of the various factors studied, it has been shown that soil temperature had decidedly the greatest influence on the incidence of wound cork in roots of alfalfa and sweet clover. Sanford (*9*, *10*) reported that these crops were much more susceptible to the attack of *P. meliloti* and *Sclerotinia* sp., immediately following the overwintering period, at which time the soil temperature is relatively low. Therefore, the observed inhibition of wound cork at low soil temperatures might have some significance in this respect, if wound cork forms an effective barrier to these pathogens under prevailing temperatures in the field. Although wound cork formed more rapidly at the higher soil temperatures employed in the different experiments, it did not appear to form very rapidly under average summer conditions. At 18° C., which is a high soil temperature, even in midsummer, at Edmonton a really effective layer was not formed until 13 days after wounding. Although weak parasites and saprophytic fungi would probably be walled out, the relatively long time taken for effective wound cork to develop should allow rapidly progressing pathogens, such as *P. meliloti* and *Sclerotinia* sp., ample time to invade the inner tissues of the root. In this connection, Artschwager (*1*) concluded that the rapidity with which wound cork developed was of more importance than the actual thickness of the layer.

The importance of adequate aeration of wounded plant tissues, in favouring the formation of wound cork, was emphasized by Priestley and Woffenden (*7*). In this connection, it is suggested that reduced aeration in the moist soil might account for the slightly more rapid formation of wound cork observed under dry soil conditions in these studies. Also, wound cork was often retarded when a large amount of the wound substance, previously mentioned, was deposited at the surface of a wound and thus possibly reduced aeration of the underlying tissues. Further, the fact that wound cork was often retarded in the deep longitudinal incisions, but developed better in the shallow tangential cuts, also suggests the importance of proper aeration. However, under normal field conditions the factor of aeration would seem of little or no significance in the root rot problem.

The common occurrence of groups of fibres in roots of alfalfa and sweet clover probably reduces the effectiveness of wound cork in these areas. These fibres are incapable of wound cork formation, and many cases were observed where they had interrupted a wound cork layer, leaving an unprotected opening for the entrance of pathogens. However, in certain cases the wound cork layer detoured around the obstructing fibres.

The results obtained in this study indicate that, under average field conditions in Alberta, the relation of wound cork to the development of root rot in alfalfa and sweet clover is relatively unimportant. The results of investigations on the direct influence of wound cork on the invasion of root-rotting pathogens of these plants will be reported later.

Summary

1. The incidence of wound cork in roots of *Medicago* and *Melilotus* was studied, with particular reference to the influence of the temperature and moisture content of the soil, the age, condition, and variety of the plants.

2. The rapidity of wound cork formation was greatly influenced by soil temperture, with which it was directly correlated. Wound cork was completely inhibited at 1° C., formed in 18 days at 9° C., and in 8 days at 18° C.

3. Dry soils were slightly more favourable than moist soils for wound cork development, but the difference was not very significant in these studies.

4. Wound cork formed more rapidly in roots of young plants of *Melilotus* during the first season, than in roots of overwintered plants during the second season. This difference was not apparent in *Medicago*.

5. The formation of wound cork was retarded in roots of *Medicago* and *Melilotus* that had been frozen, and it did not form in non-growing roots.

6. There was no significant difference among varieties of *Medicago* and *Melilotus* in ability to form wound cork, but marked variability occurred in roots of different plants of the same variety.

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SOME OBSERVATIONS ON THE GROWTH OF MARQUIS WHEAT WITH SPECIAL REFERENCE TO ROOT DEVELOPMENT[1]

P. M. Simmonds and B. J. Sallans[2]

Introduction

This contribution is a continuation of our studies (*9*) (*10*) of Marquis wheat in respect to developmental changes and their possible bearing upon the interpretation of root disease reactions. Lesions and other symptoms of disease are omitted from the records, for the time being, so that complete attention can be given to the usual seasonal growth changes.

In respect to earlier work we refer the reader to the rather complete review of literature made by Miller (*5*) and more recently by Weaver (*11*). The economic significance of root development has been emphasized by Howard and Howard (*3*).

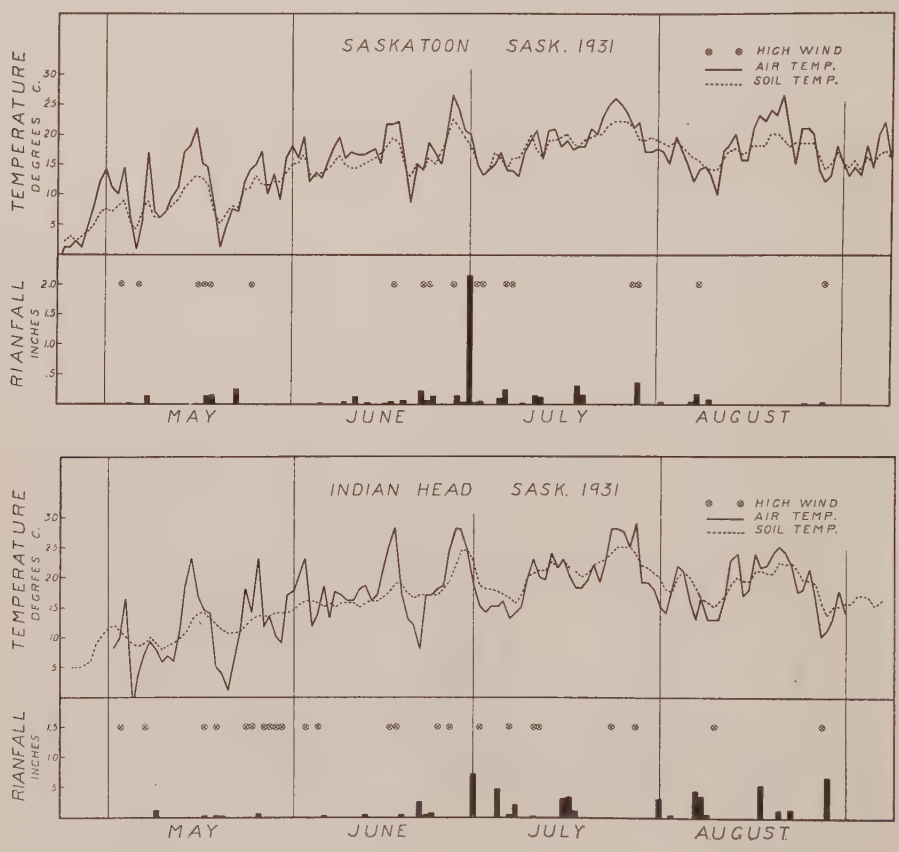

Figure 1. *Rainfall, air temperatures, soil temperatures and high winds for the crop season of 1931 at Saskatoon and Indian Head.*

The Development of Marquis Wheat in 1931

The fields selected for observation were located at Saskatoon and Indian Head, Saskatchewan. Some meteorological records for the season at each location are

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given in Figure 1. Measurements were made upon fifty representative plants in each case. The height was taken from the soil level to the tip of the uppermost leaf until the head appeared, then to the tip of the head. Counts of seminal roots were frequently omitted from the final records as there is rarely an increase late in the season.

Field A, Saskatoon.—This was a small plot of Marquis wheat grown on summer-fallow. Seeding was done on April 28 and growth records were made at definite periods thereafter. The results are given in Table 1.

TABLE 1.—*Data obtained on the development of Marquis wheat at Saskatoon, Field A, 1931. The records are an average on fifty plants taken on each date.*

Date	Weeks after seeding	Height cm.	Number of culms	Plants with coleoptile shoot %	Number of roots		Heads ripe %
					Seminal	Crown	
May 5	1	—	—	—	3.3	0	—
May 12	2	4.8	1	—	4.1	0	—
May 19	3	11.3	1	—	4.5	0	—
May 26	4	15.4	1.2	—	4.8	0.08	—
June 2	5	16.1	1.08	—	4.7	—	—
June 16	7	25.0	1.5	10	—	2.5	—
Aug. 8	16	47.3	1.6	—	—	5.0	73

TABLE 2.—*Data obtained on the development of Marquis Wheat at Saskatoon, Field B, 1931. The records are an average on fifty plants taken on each date.*

Date	Weeks after seeding	Height cm.	Number of culms	Plants with coleoptile shoot %	Number of roots		Heads ripe %	Yield per acre bushels
					Seminal	Crown		
May 16	4	13.4	1.1	—	4.4	0	—	—
May 23	5	14.3	1.5	—	5.0	0.1	—	—
May 30	6	18.9	3.1	—	5.3	1.4	—	—
June 23	9	35.4	3.1	—	5.6	5.4	—	—
June 30	10	41.3	3.0	—	5.4	6.5	—	—
July 7	11	41.1	3.4	—	4.9	10.1	—	—
July 14	12	43.6	4.4	26	5.2	11.1	—	—
Aug. 8	15	52.8	4.3	—	4.8	16.7	75	11

Field B, Saskatoon.—This was a field of several acres and followed a crop of wheat in rows. Seeding was done on April 18. The results are given in Table 2.

Field C, Indian Head.—The records obtained in this field were upon a crop of Marquis produced on summer-fallow. It was seeded April 13. The results are given in Table 3.

TABLE 3.—*Data obtained on the development of Marquis Wheat at Indian Head, Field C, 1931. The records are an average on fifty plants taken on each date.*

Date	Weeks after seeding	Height cm.	Number of culms	Number of roots		Yield per acre bushels
				Seminal	Crown	
May 15	5	8.4	1.1	3.1	0	—
May 28	7	8.4	—	3.4	0	—
June 12	9	13.0	1.1	3.1	0	—
June 25	11	23.5	1.6	3.7	5.5	—
July 10	13	37.5	1.5	—	—	—
July 24	15	54.5	—	3.3	9.8	10

TABLE 4.—*Data obtained on the development of Marquis Wheat at Indian Head, Field D, 1931. The records are an average on fifty plants taken on each date.*

Date	Weeks after seeding	Height cm.	Number of culms	Number of roots		Yield per acre bushels
				Seminal	Crown	
May 15	5	9.2	1.0	3.1	0	—
May 28	7	13.0	1.0	3.4	0.1	—
June 12	9	15.5	1.0	3.2	0.0	—
June 25	11	26.0	1.0	3.1	1.3	—
July 10	13	38.0	1.0	—	—	—
July 24	15	43.7	1.6	—	5.9	nil

Field D, Indian Head.—This field of Marquis wheat was grown on land which produced a crop of corn the year before. It was seeded April 14. The records are given in Table 4.

Development in every case was poor which is clearly reflected in the yields obtained. The explanation lies mainly in an inadequate moisture supply, as insufficient seasonal rainfall, its unfavourable distribution or a lack of reserve soil moisture. The plants on the whole were subnormal in growth.

ROOT GROWTH OF MARQUIS WHEAT IN 1931

A study of the development of Marquis wheat roots was made at Saskatoon and Indian Head. Weaver's (*11*) method of examination was employed. A trench was dug near the plants selected for study, then the soil was carefully picked away until the main roots were exposed. As the work progressed notes and measurements were made, then later a representative plant was reconstructed in a diagram. Several plants were excavated each time in order to determine what might be considered a representative specimen.

Saskatoon Plants.—The plants studied here were taken from Field A mentioned in the previous section. The soil and soil profile on this plot were described by Prof. A. H. Joel, of the Soils Department, University of Saskatchewan, as follows:

"A dark brown, light loam soil of the Plains-Park transition zone. The profile has the dark brown soft cloddy surface, the brown long cloddy rather hard sub-surface, and the gray calcareous subsoil usual for the well-drained soils of this zone. The topography is undulating. The fertility, drought resistance and general productive capacity seem to be about average for the province as a whole".

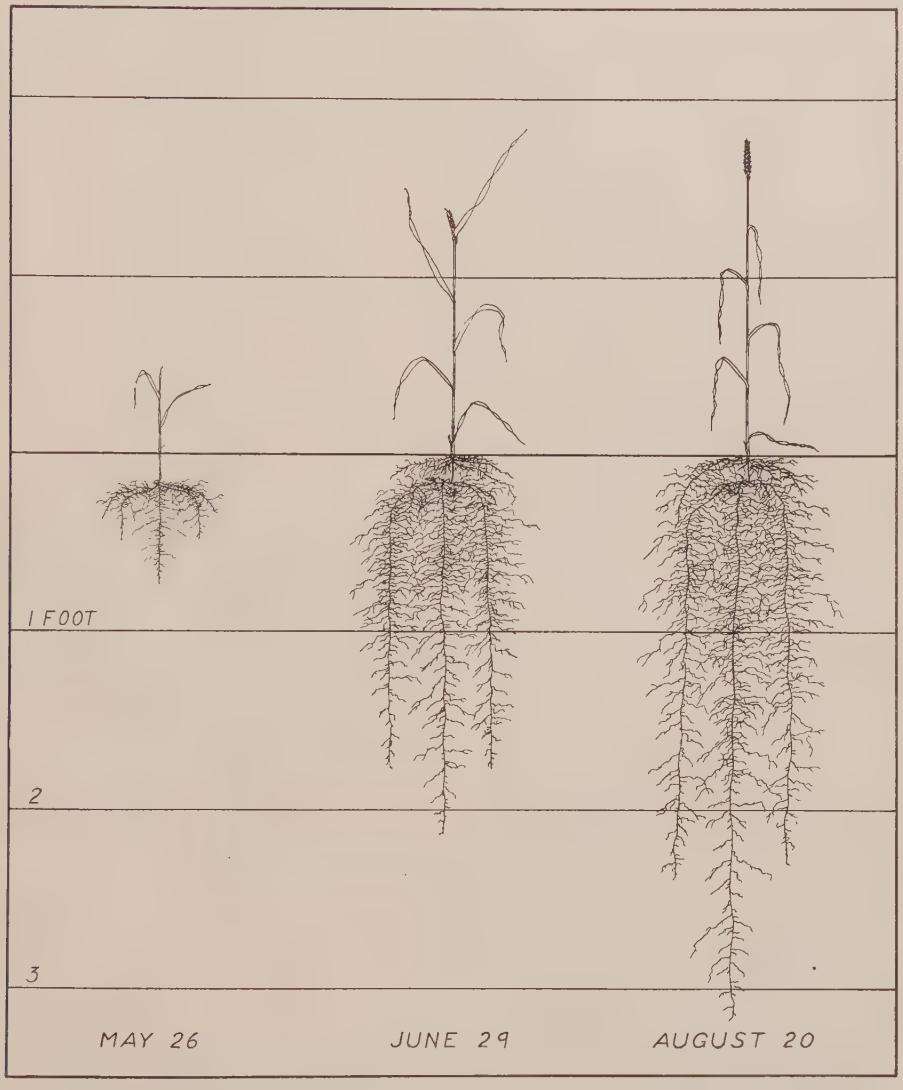

FIGURE 2. *The development of Marquis wheat through the season of 1931 at Saskatoon. The observations were made on plants growing in a plot seeded at the usual rate on summer-fallow. The rainfall was below normal requirements, resulting in a weak crown root development. Severe competition for moisture prevented normal tillering and those tillers which did start, died prematurely.*

The first examination was made on May 26, four weeks after seeding. There was an average of five seminal roots, the primary one being down to a depth of seven inches. Severe dust storms and a slight frost had retarded development slightly

(Figure 2, May 26). A mid-season examination was made on June 29, nine weeks after seeding. At that time the poor development caused by the exceedingly dry weather was quite evident. The plants had only one short culm bearing a small head. Only three of the seminal roots had developed to any extent, the primary one being down to a depth of two feet, while the other two were slightly shorter. However, the seminal root system may be considered as well established. These roots averaged about six to eight small laterals to the inch. The laterals, of course, vary a great deal in length, and branch and re-branch. The remaining two seminals were abortive. The fourth and fifth seminal roots, it is believed, do not as a rule grow to a great length unless one or more of the first three are injured or attacked by fungi. The crown root system, as found at this date, can be considered as practically functionless. The surface soil was very dry and the six crown roots present were short and otherwise feebly developed. The length of the longest in most cases did not exceed six inches (Figure 2, June 29). The final examination was made on August 20, approximately sixteen weeks after seeding. The crop at this time was ready to cut. Many of the plants had one tiller besides the main culm; this tiller was late and green. A plant with a single culm, however, was selected as representative of the plot. There was a marked increase in growth in both root systems since the last examination. The primary root of the seminal system had grown one foot, while the accompanying two had elongated proportionally. This probably represents the maximum depth as the plants were fully mature, except for a green tiller here and there. It will be seen that the seminal roots are well developed and that the poor general development of the plant is a reflection of the late and meagre growth of the crown roots. The rains that promoted the increase in crown root growth came too late to allow this system to perform its usual function in supporting tiller development (Figure 2, August 20).

Some plants of Marquis wheat growing singly and without competition may

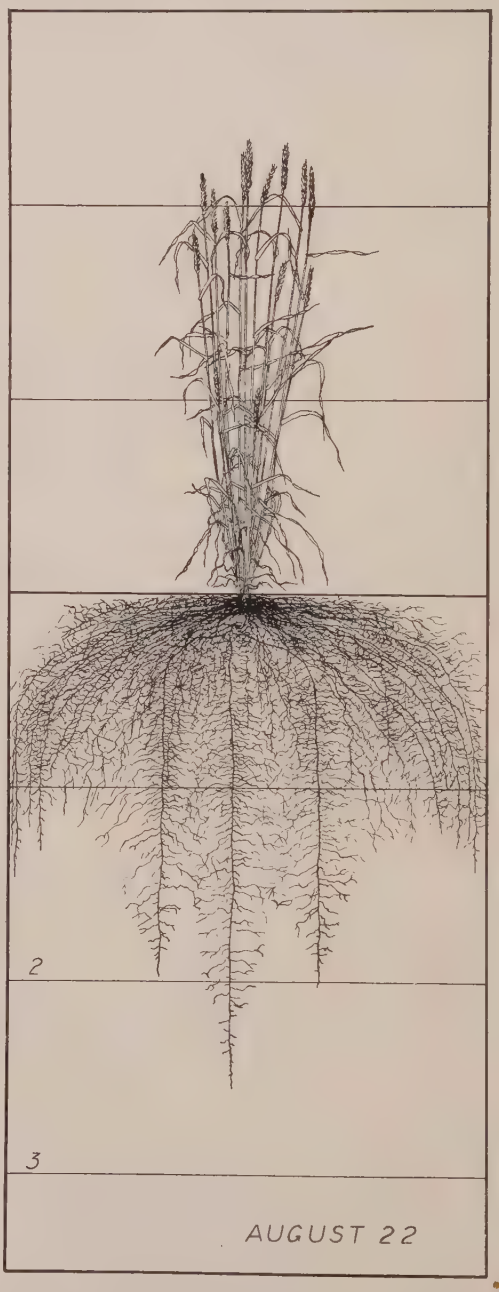

FIGURE 3. *A Marquis wheat plant growing without competition at Saskatoon in 1931. It bore fourteen stems, all headed, ninety-eight crown roots and five seminal roots. It was still green when the ordinary crop was ripe.*

be compared with the above results in respect to root and top development. These were not followed through the season but were excavated on August 22 when ordinary fields were fully ripe. In Figure 3, a diagram representative of such plants is given. The maximum height was 28 inches. There were 14 culms, all headed,

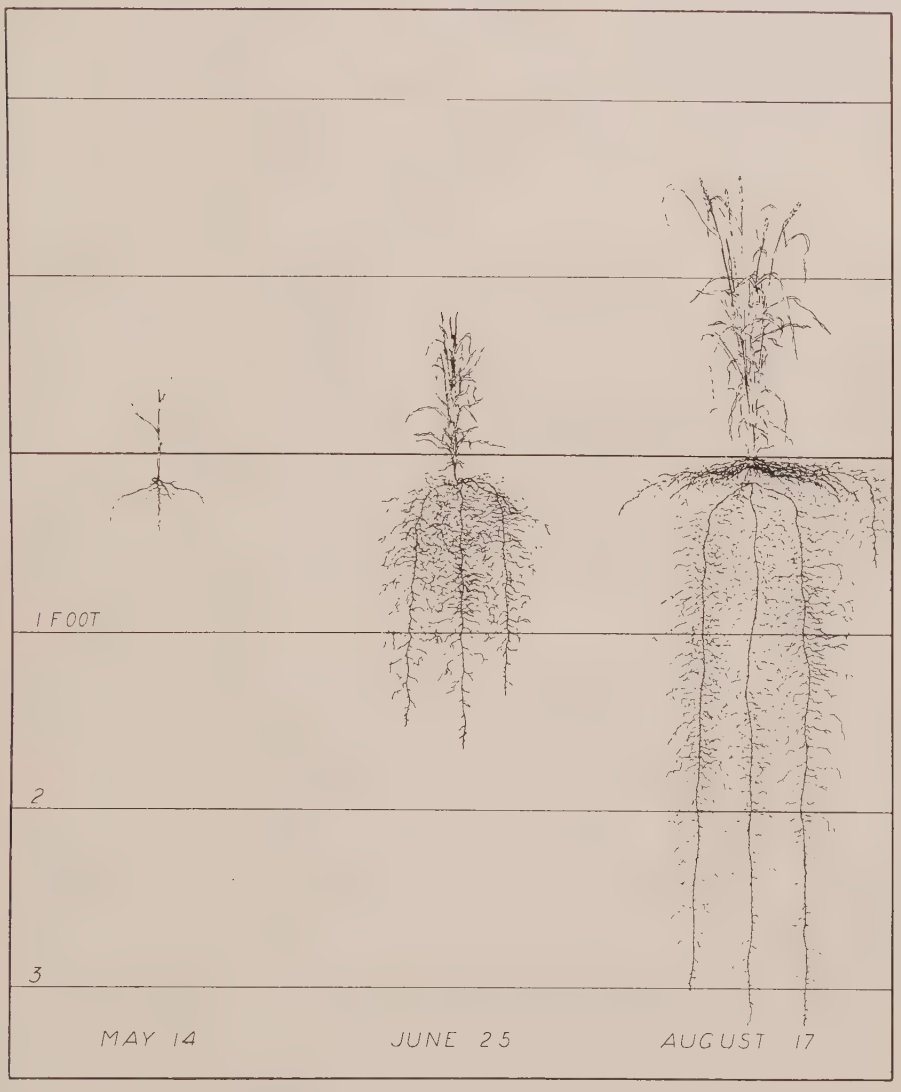

FIGURE 4. *The development of Marquis wheat through the season of 1931 at Indian Head. The observations were made on plants growing on summer-fallow in rows which were one foot apart. The seeding was at the rate of two hundred seeds to the rod row. The competition was not so severe here as in the case of the Saskatoon specimens. The plants suffered severely from drought and dust storms early in the season. Delayed rains encouraged late crown root development.*

with the earliest still in the firm dough stage. There were five seminal roots, the primary one reaching a depth of slightly over two and one-half feet, with the accompanying pair at about the two-foot level. The other pair did not develop beyond

a few inches. There were 98 crown roots. Several of these reached a length of two feet and many extended down one foot. The radius of this system was about eight to twelve inches. The roots bore abundant lateral rootlets. The lack of competition and late rains explains this extensive crown root and tiller development, a type of growth which does occur rarely under ordinary cropping practice. Such growth predisposes the plant to rust and frost injury.

Indian Head Plants.—The plot of Marquis wheat used at this location was sown on April 23. Seeding was done at the rate of 200 seeds to the rod row and the rows were one foot apart. The first excavation was made on May 14, three weeks after seeding. At this stage the seedlings were showing the effects of adverse weather conditions. The shoot was only four inches in height. There were four seminal roots, the primary one being four inches in length (Figure 4, May 14).

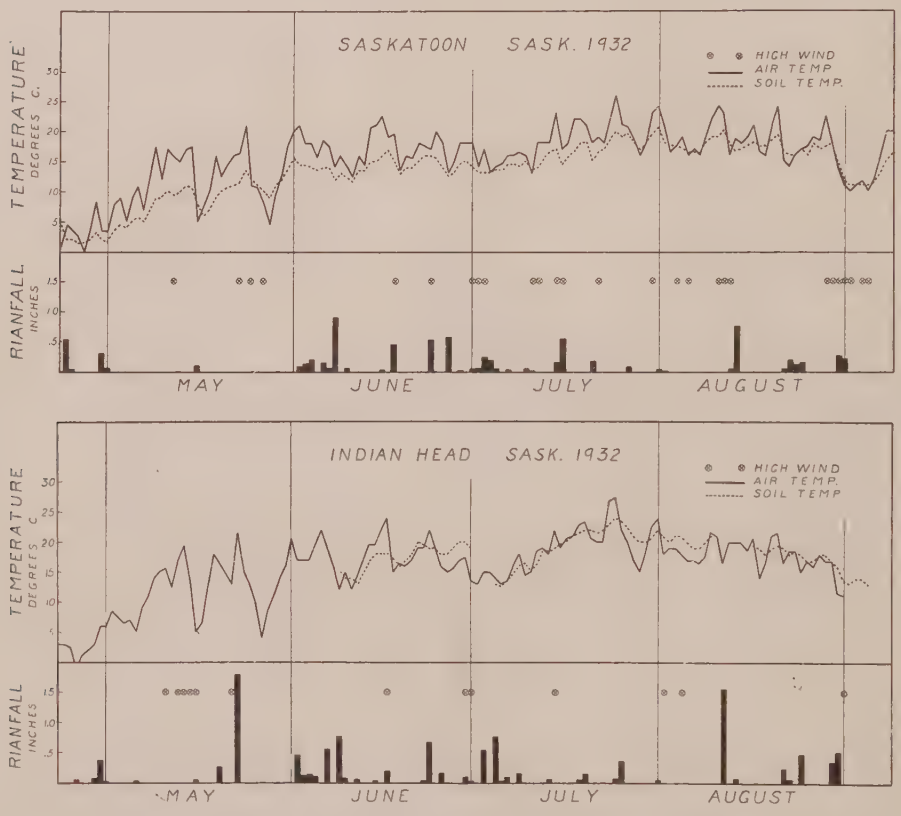

FIGURE 5. *Rainfall, air temperatures, soil temperatures and high winds for the crop season of 1932 at Saskatoon and Indian Head.*

This plot was completely blown out and had to be reseeded. The next excavation was made on June 25, six weeks after reseeding. The crop at this time was very backward. There was evidence of a continued struggle on the part of the plants to survive on account of insufficient moisture. A few showers of rain encouraged tiller development, but they were quite inadequate to sustain continuous growth. Six culms were present, the tallest being ten inches. The plant was almost entirely dependent upon the seminal roots, as the seven crown root stubs, emerging coincident with tiller development, were completely checked in the dry surface soil. There were four seminal roots, the primary reaching a depth of 18 inches, followed

closely by the usual first pair. The remaining seminal root was abortive (Figure 4, June 25). There had been repeated soil drifting and many of the lower leaves were dead. The final examination was made on August 17, approximately 14 weeks after reseeding. The plant selected as representative had eight culms, five bearing heads and three in the shot-blade stage. The later heads were in the milk stage. The maximum height was 22 inches. There were only three well developed seminal roots all penetrating to the three foot level. There were twenty-nine crown roots, varying in length from two to fifteen inches (Figure 4, August 17). The abnormal development of this plant may be explained by the unfavourable distribution of the rainfall. The late rains encouraged tiller and crown root growth to no particular advantage. This reaction would not have been so great if the plants had developed under the usual competition instead of in rows.

The Development of Marquis Wheat in 1932

A study similar to that made in 1931 was conducted during the summer of 1932. Observations and measurements were made at definite intervals upon plants growing at Saskatoon and Indian Head, Saskatchewan. The procedure was the same as that used in previous work. In some cases additional data were taken. In regard to the height it was thought that a more accurate measurement would be obtained by recording the progress of the terminal bud of the main culm as well as the gross height. Furthermore the percentage of plants showing dead tillers was recorded for the Saskatoon specimens. The more important meteorological data were recorded for the crop season (Figure 5).

Field E, Saskatoon.—This was a small plot of Marquis wheat grown on summer-fallow. In so far as competition was concerned it would compare favourably with an ordinary field. It was seeded May 3 after which records were taken periodically. The results are given in Table 5.

Table 5.—*Data obtained on the development of Marquis wheat at Saskatoon, Field E, 1932. The records are an average on fifty plants taken on each date.*

Date	Weeks after seeding	Height		Number of culms	Plants with coleoptile shoot %	Plants with dead tillers %	Number of roots		Heads ripe %
		Gross cm.	Bud cm.				Seminal	Crown	
May 24	3	16.1	S.L.*	—	—	—	4.1	0	—
June 1	4	18.1	S.L.*	2.3	34	—	4.9	0.8	—
June 14	6	32.7	6.1	2.3	—	—	4.7	5.2	—
June 28	8	62.8	45.8	1.3	—	—	4.1	9.7	—
July 13	10	77.9	77.9	1.2	—	—	5.0	9.4	—
July 26	12	80.8	80.8	1.2	—	48	5.6	10.2	—
Aug. 9	14	80.2	80.2	1.2	—	—	5.6	12.8	85

* *Soil Level.*

Field F, Saskatoon.—This was a large field of Marquis wheat following summer-fallow. It was seeded May 4. This may be considered about an average field for the district although the stand was reduced slightly by wireworms. The results of the measurements obtained are given in Table 6.

Field G, Indian Head.—This was a plot of five and one-half acres of Marquis wheat following summer-fallow, being a part under regular rotations as used on the

Dominion Experimental Farm. It was seeded on April 19. The measurements obtained are given in Table 7.

Field H, Indian Head.—This was a small block of about one acre seeded with elite stock Marquis. There had been a crop of potatoes on the land the year before. It was sown on April 26. The measurements obtained are shown in Table 8.

The growth in 1932 as recorded in the above tables was much better than for the same localities in 1931. This was largely the result of the rainfall being more abundant and better distributed. In Field E, at Saskatoon, however, nearly

TABLE 6.—*Data obtained on the development of Marquis Wheat at Saskatoon, Field F, 1932. The records are an average on fifty plants taken on each date.*

Date	Weeks after seeding	Height		Number of culms	Plants with coleoptile shoot	Plants with dead tillers	Number of roots		Heads ripe	Yield per acre
		Gross	Bud				Seminal	Crown		
		cm.	cm.		%	%			%	bushels
May 25	3	13.3	S.L.*	1.3	—	—	3.5	0	—	—
May 31	4	17.5	S.L.*	2.5	—	—	3.9	0.2	—	—
June 14	6	33.8	S.L.*	5.3	54	—	3.6	11.2	—	—
June 28	8	60.4	31.4	4.7	—	—	3.7	22.7	—	—
July 13	10	89.4	89.4	3.8	—	—	4.4	24.9	—	—
July 26	12	97.3	97.3	4.8	—	36	5.1	28.5	—	—
Aug. 9	14	95.7	95.7	4.1	—	—	—	29.6	97	26.7

* *Soil Level.*

TABLE 7.—*Data obtained on the development of Marquis Wheat at Indian Head, Field G, 1932. The records are an average on fifty plants taken on each date.*

Date	Weeks after seeding	Height	Number of culms	Number of roots		Heads ripe	Yield per acre
				Seminal	Crown		
		cm.				%	bushels
July 9	12	68.9	1.1	4.6	10.4	—	—
July 22	14	71.7	1.0	5.2	11.4	—	—
Aug. 5	16	65.0	1.0	4.4	10.9	94	22.5

TABLE 8.—*Data obtained on the development of Marquis Wheat at Indian Head, Field H, 1932. The records are an average on fifty plants taken on each date.*

Date	Weeks after seeding	Height	Number of culms	Number of roots		Heads ripe	Yield per acre
				Seminal	Crown		
		cm.				%	bushels
July 8	11	76.9	2.1	4.1	10.1	—	—
July 22	13	105.9	1.2	4.6	11.6	—	—
Aug. 5	15	97.5	1.1	4.5	11.9	18	22

50% of the plants showed dead tillers on July 26, the result of moisture deficiency and fungous invasion. In Field F, the crop was somewhat thinner and tillering was encouraged. In the Indian Head fields there were symptoms of drought injury early in July. The seasonal rainfall had been favourable, but there was a distinct lack of reserve soil moisture. The yield for Field G was 22½ bushels per acre of No. 1 grade. Drought had reduced greatly the yield in recent years. The five-year average ending in 1929 for this field was approximately 38 bushels per acre.

The two latter fields discussed, although better than the average, were quite typical of a large acreage in Southern Saskatchewan. The damage caused by drought and high warm winds varied from moderate injury to total loss. In excavations in Field H for root study, it was noticed that the upper part of the two-foot level was deficient in moisture, whereas lower and beyond three feet moisture conditions were fair. Soil moisture data available at the Dominion Experimental Farm, Indian Head, supported these observations. The strong development of seminal roots (see Figure 7) probably was of great assistance in maintaining growth especially in the filling of the kernels.

Root Growth of Marquis Wheat in 1932

In continuing the work commenced in 1931 root studies were made both at Saskatoon and Indian Head. The methods used were the same as those employed previously. Several plants were excavated each time and from the data obtained a representative specimen was reconstructed in a diagram.

Saskatoon Plants.—The plants studied here were taken from field E, mentioned in the previous section. This was also the field from which the plants were taken for root studies in 1931. The plot had been sown on May 3 and the first examination was made on June 1 after four weeks of growth. The seedlings on this date averaged six inches in height. No crown roots were established. There were five seminal roots, three of which were well developed. The primary seminal root had reached a depth of about nine inches. There were approximately four distinct laterals to each inch of root and these varied from one to five inches in length. They were most abundant near the seed. During this period of seedling growth there had been very little rainfall. The surface soil was dry and consequently there was little encouragement for crown root growth. The plants were quite dependent upon the seminal system (Figure 6, June 1). The mid-season examination was made on July 15 or approximately ten weeks after seeding. The plant selected for illustration had two culms headed, the tallest being about thirty inches with the other a few inches shorter. Other tiller shoots by this time had died back through lack of moisture or were invaded by fungi. It was evident that one- or two-culm plants would be representative of the plot unless excessive rainfall occurred. The seminal root system was well developed; the excavated plants showing from five to six roots. Only three, however, penetrated to the lower depths, being well within the second-foot level. The maximum root length at this time was 28 inches. There was an average of approximately eight laterals to each inch of main root; they were more numerous in the upper layers. The fourth, fifth and sixth seminal roots remained comparatively short. We believe, nevertheless, that if one or more of the first three are injured the remaining ones would tend to penetrate much deeper. The crown roots at this date were not particularly well developed as the plants were under rather severe competition. There was at this time an average of ten to fifteen crown roots but only one or two were of any length and well supplied with laterals. There was an average of six laterals to each inch of root (Figure 6, July 15). The final examination was made on August 11 when the plants were mature. There was a measurable increase in growth since the last observations were made. The tallest culm was nearly three feet in height and the longest root was of approximately the same length. The maximum root growth is usually reached before the ripening processes set in. We observe for this date a slight increase in length in both seminal

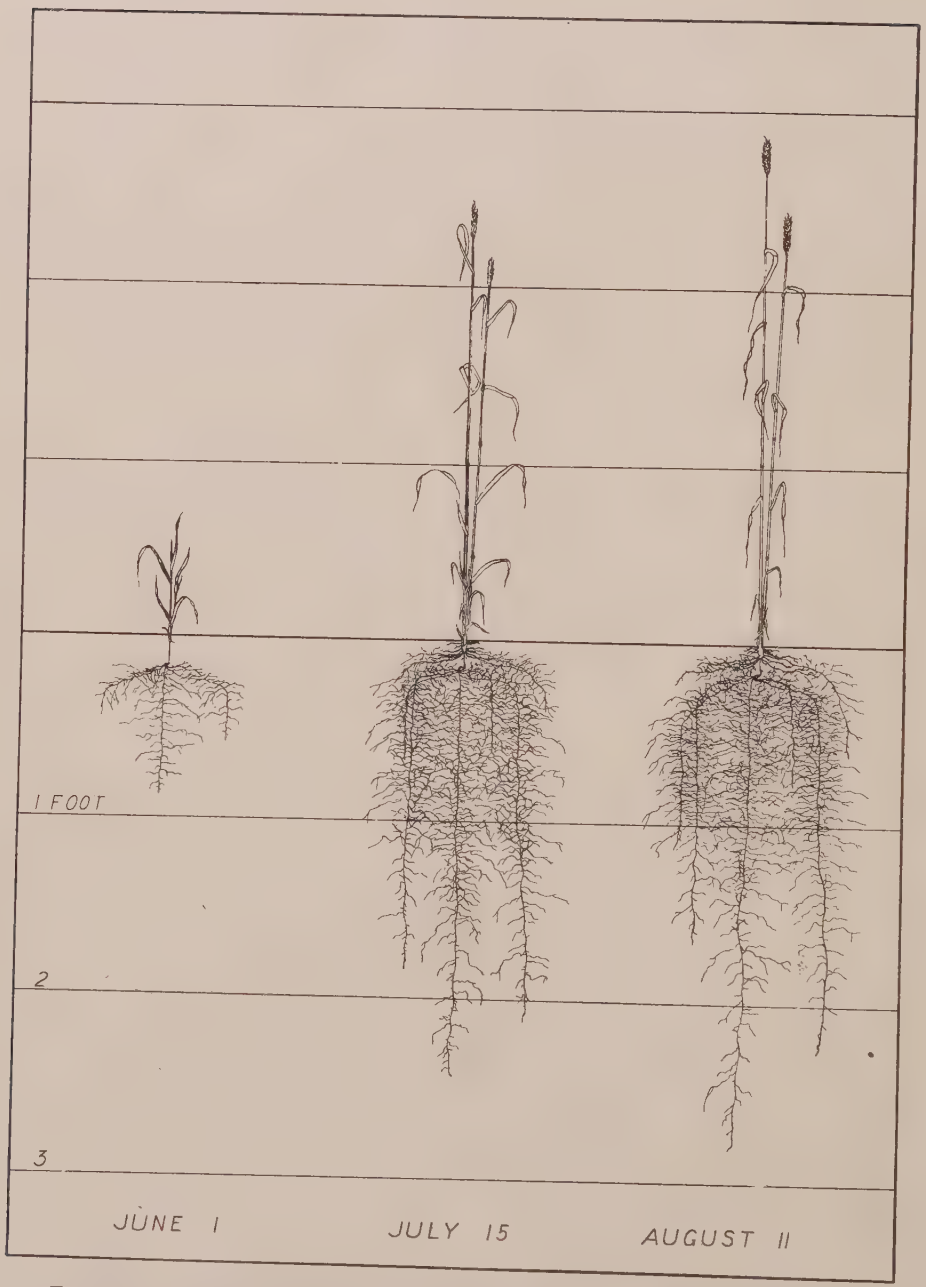

FIGURE 6. *The development of Marquis wheat at Saskatoon through the season of 1932. The plot from which the observations were made was on summer-fallow and seeding was at the usual rate. There was evidence of competition but the rainfall was more favourable than in 1931 with consequently a better general growth. The heads were small and the yield in all probability would have been low but of good quality.*

and crown roots. The deepest seminal root had a total length of thirty-two inches. Undoubtedly there would be some increase in the laterals as well. The tips of the seminals were quite fresh and white and probably were still alive. The excellent development of the seminal root system must have been of significant importance to the plant in view of the fact that normal crown root growth was prevented by inadequate moisture (Figure 6, August 11).

FIGURE 7. *The development of Marquis wheat at Indian Head at midseason and at harvest time in 1932. The observations were made on plants growing under ordinary field conditions. The land had produced a crop of potatoes the year before. The development of the crop was favourable although suffering somewhat from drought because of insufficient reserve soil moisture. The previous season had been one of severe drought. The yield from this field was at the rate of 22 bushels per acre and was of good quality.*

Indian Head Plants.—The plants used in this study were taken from Field H mentioned above. It was sown on April 26. The seedling examination unfortunately had to be omitted. The early spring had been very windy and dry but after May 22 growing conditions were quite favourable. The first observations recorded were made on July 8. The main culm was headed and had reached a height of approximately thirty inches. At least one and frequently two well developed tillers were also evident. In comparison with the Saskatoon plants at midseason the seminal roots were not so well developed. The maximum penetration was approximately 26 inches. The crown roots, however, were much better, showing a relatively strong growth with an occasional root extending to the two-foot level. The good crown root growth here was in all probability promoted by the timely rains. At the same time top growth would be encouraged. A period was reached, however, when the rainfall was not equal to the demands. The plants were subject to strong competition. The excavations at this time revealed the fact that the two-foot level appeared lacking in moisture and this deficiency was shown by the plants especially at midseason when growth is usually very active (Figure 7, July 8). The final examination was made on August 14 when the crop was mature. The rainfall in the intervening period had not been in excess of the plants' requirements and

new growth was not encouraged. In the specimen used for illustration the main culm had reached a height of over three feet with another headed culm slightly over two feet. The period of insufficient rainfall and competition resulted in the death of many promising tiller shoots. Fungous invasion was also a contributing factor to this injury. The majority of the plants in this field were of the single culm type. Late rains, however, in a case like this probably would not be beneficial as, barring rust infections, the secondary growth alone would tend to lower the grade. The crown roots may be considered as well developed in view of the conditions, but they had not grown much since midseason. The seminal roots on the other hand being better situated continued to penetrate through the slightly moist two-foot level and into the damper three-foot layer. The maximum length at this time was 38 inches. It is very likely that the seminal roots supported the plant in the final stages of ripening, assisting the overburdened crown roots in assuring the complete development of the kernels (Figure 7, August 14).

Discussion

The investigations were carried on in seasons of rather extreme drought which had a marked influence on growth. The general mode of development was, however, quite regular. By utilizing the records on the progress of the terminal bud of the main culm along with supplementary observations, it was possible to divide the development of the plants at Saskatoon for 1932 into three main divisions: (1) From May 4 to June 12 was a period of seedling development towards the end of which crown roots were being established; (2) from June 12 to July 12 one observes a period characterized by the rapid elongation of the culms along with tillering and crown root growth; and (3) a final phase of flowering and ripening from July 12 to August 9 (Figure 8). Such periods may be subdivided as has been done by Pope (*7*) in studying the growth curve of barley.

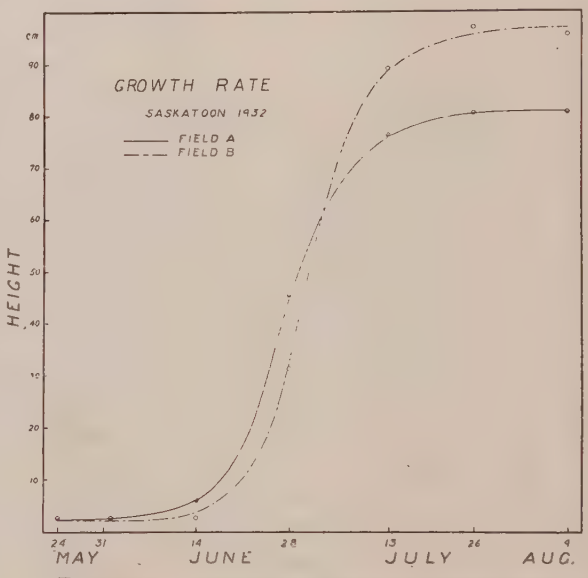

Figure 8. *Average growth rate of the main culms for plants selected from two fields at Saskatoon in 1932. The curves show that the season's growth can be divided into three main periods, from seeding to crown root development, elongation of the culms, and ripening (See Tables 5 and 6).*

The first phase, covering a period of about six weeks, is featured by a strong seminal root growth. At the same time there is good expansion of leaf tissue but practically no elongation of the shoot. This is usually a period of cool soil temperatures which for the most part remain below 15°C. Wheat roots grow well at such temperatures according to Jones *et al* (*4*) and Russell (*8*). Soil moisture is usually sufficient during this period. Thus it is seen that with the exception of injury or parasitism, conditions in Western Canada are ordinarily favourable for seedling growth. The number of seminal roots, which function early in the season, varies from three to five. Wiggins (*12*) found that five was the usual number for several species of wheat. Root growth was probably in excess of shoot growth during this period. In some greenhouse experiments Harris (*1*) has shown that in wheat

harvested at different stages, the proportion of roots was greater when the plants were young.

The plants enter the second phase of development at a time when soil and air temperatures are higher. This period was characterized chiefly by the rapid elongation of the culms, tiller and crown root growth and flowering. The seminal roots, however, continued to grow. The poor and retarded development of crown roots in our 1931 material especially can be explained by the inadequacy of surface soil moisture, (Tables 1, 3 and 4 and Figure 2). This situation inhibited tiller development and made the main culm almost entirely dependent upon the seminal system. On the other hand, abundant rains with high temperatures during this period would have promoted excessive growth. In such cases with the transpiration rate high, as would occur during a period of drought, an extensive root system soon exhausts the available moisture and the top is desiccated, producing a condition commonly termed "firing". A large area in Southern Saskatchewan suffered from "firing" in 1932. Under such conditions it would appear that the plants although restricted in growth are largely supported and frequently saved by a well developed seminal root system (Figure 7).

After flowering, the plants enter the ripening or final stage of their growth. The culms cease to elongate. Generally speaking the primary or main shoot dominates the growth so that all tillers are of subordinate rank and usually succumb when there is only sufficient nourishment to support the one shoot. Under conditions of keen competition single culm plants become the rule. Ordinarily there is very little increase in growth during the ripening period with the exception of the filling of the kernels. Increase in root growth is slight, Weaver (*11*).

Usually the yield of wheat will be low after a period of drought, but the quality will be good. Such conditions interfere chiefly with crown root development. In this connection it might be well to mention some observations given by Howard, (*2* p. 101) in discussing the wheat crops of India,—

> "The chief points of interest in the distribution of varieties concern the bread and macaroni wheats. The former are typical of the alluvial soils of the plains, the latter of the dry black soil areas south of the Jumna. The separation results from differences in the soil type. On the alluvium, bread wheats form the usual secondary root-system and proceed to tiller. Fairly large yields of moderate-sized grain result. On the black soils, except in certain favoured localities, macaroni wheats are the rule. The upper soil dries so rapidly after sowing that there is hardly any development of the secondary root system, and practically no tillering. The crop develops slowly on the primary roots; the grain is always large and the yields extremely low".

The seminal roots are often referred to as temporary roots which disappear as the permanent (secondary or crown) roots are established. It is possibly true that under certain conditions and towards the end of the season most of the functions of the seminal system may be assumed by the crown roots as pointed out in a previous paper. In a humid climate with abundant surface moisture, it is quite possible that a strong crown root system is adequate and consequently the seminals cease to function and atrophy. Their importance in the dry territories, at least for some varieties, however, would appear to be unquestionable. The strong development of seminal roots may be one of the reasons why Marquis wheat has been so successfully grown in western Canada. Weaver (*11*), Pavlychenko (*6*) and others have found an extensive and continued development of the seminal root system in wheat.

A better understanding of the extent and functions of the root system of wheat should be of assistance not only to the pathologist but to the agronomist and plant breeder as well.

Summary

1. Results of a study of the growth of Marquis wheat at Saskatoon and Indian Head during the seasons of 1931 and 1932, are given. It is shown that dry weather interfered noticeably with growth during the period of investigation. In 1931 the data shows a distinct reduction in yield, and the general growth features reflect the same reaction. In 1932 the yield was below normal but much better than for 1931. Records are given on the increase in height, the number of culms and the number of roots along with supplementary notes.

2. Particular attention was given to the study of root development. It is shown that the general mode of root growth was the same for each location each season. The seminal root system was well developed while the crown root growth was feeble. The maximum penetration for seminal roots was slightly over three feet. Plants grown free from competition show a well developed crown root system. The plants receive, it would appear, a great deal of support from the seminal system especially during dry periods.

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SEED INJURY IN WHEAT AND INFECTION BY *HELMINTHOSPORIUM SATIVUM* P.K. & B.[1]

H. W. MEAD[2]

INTRODUCTION

From the standpoint of yield or quality, the health of the seed is a factor of first importance. When all of the other factors, such as nutritive relations, moisture, and temperature are favourable for successful production, the crop may be a failure because of the parasites which are seed-borne or because of natural or artificial injury of the seed. Studies on the relation of seed-coat injury and viability of seeds of wheat and barley to their susceptibility to moulds and fungicides were conducted by Hurd (*2*). She found that death or injury resulting from seed treatment or other cause renders previously immune seeds susceptible to attack by such soil inhabiting saprophytes as *Penicillium* and *Rhizopus*. Machacek and Greaney (*4*) studied the relation of mechanical injury to foot rot of cereals. They found that when injured seed of wheat, hull-less oats and barley was planted in soil infested with *Fusarium culmorum* var. leteius, the damage from foot rot and pre-emergence blight to the resulting seedlings was greater than when uninjured seed of the same varieties was sown. Simmonds and Scott (*8*) refer to Kiessling's (*3*) determination that formaldehyde, in ordinary seed treatment dosage caused injury to seed grain and in their own experimental work, they found that ordinary formalin treatment injured wheat seeds, and gave poor protection against fungi which caused root rots. They also pointed out that Coons and McKinney (*1*) in laboratory tests found that wheat was more sensitive to formaldehyde than oats, barley or rye.

MATERIALS AND METHODS

The present experiments conducted in 1932 dealt with the relation of natural seed injury and seed injury due to formalin treatments, to the attack of wheat seedlings by *H. sativum* and consequent retardation in growth and reduction of yield. The following types of naturally injured seed were used: frozen and immature Reward, and shrivelled and sprouted Marquis. The formalin treatments on Marquis wheat were: so-called "standard" formalin treatment (immersed for 10 minutes in 1:320 solution, drained, left for 4 hours in a closed vessel and dried), double strength formalin, standard formalin for double time, and two standard treatments three weeks apart. A strain of *H. sativum* which was known to be definitely pathogenic to wheat was used and the seed was inoculated in the manner described by Sallans (*6*). A portion of the sample of each of the types named above was inoculated, and a similar portion was dipped in sterile water only, to be used as checks. The same treatment was given the normal seed which was of the same variety and, as nearly as possible, of the same origin. Thus we had injured and sound seed inoculated and uninoculated. This seed was sown with two replications in six-inch pots in the greenhouse and in rod rows in plots at Saskatoon and Muenster.

RESULTS OF GREENHOUSE EXPERIMENTS

Final data from the greenhouse studies were taken at the end of three weeks growth and they included emergence, blighting and lesioning. From these, a disease rating was calculated for each group, using the method and values as outlined by Simmonds (*7*).

Some of the growth characteristics which were noted are as follows: uninoculated sprouted seed germinated and emerged about a day sooner than the corresponding normal seed; uninoculated frozen seed was slow in germinating, and

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about a week after the seedlings emerged, the leaves of many of the plants showed injury in the form of twisting, wrinkling and longitudinal splitting; seedlings from uninoculated rusted seed emerged as soon as normal seedlings, but they were spindly, with narrow leaves; all of the formalin treatments retarded germination slightly. More detailed results are presented in Table 1.

TABLE 1.—*Results of greenhouse experiments with injured and normal wheat seed inoculated with H. sativum. Six hundred seeds were tested in each of the 26 series.*

Variety of wheat	Type of seed	Series	Emergence %	Seedling blight %	Lesioning %	Disease rating %
Reward	Normal	check	83.5	1.2	49.1	27.7
	Normal	inoc.	59.5	6.7	75.6	55.5
	Frozen	check	69.5	2.2	71.3	44.6
	Frozen	inoc.	5.0	20.0	100.0	97.2
Marquis	Normal	check	98.5	—	1.2	1.9
	Normal	inoc.	88.0	2.5	80.1	38.0
	Shrivelled	check	98.5	—	2.3	8.3
	Shrivelled	inoc.	12.3	14.3	95.1	91.3
Marquis	Normal	check	99.5	0.2	71.1	18.2
	Normal	inoc.	90.0	3.9	90.1	32.2
	Sprouted	check	60.5	4.1	58.8	49.0
	Sprouted	inoc.	23.0	17.4	84.3	71.8
Reward	Normal	check	98.5	0.4	46.9	13.6
	Normal	inoc.	96.5	0.9	67.9	21.0
	Immature	check	62.5	3.2	36.6	45.1
	Immature	inoc.	50.5	4.6	62.6	60.4
Marquis	Normal	check	100.0	—	11.5	2.9
	Normal	inoc.	83.0	0.6	97.6	49.9
	Formalin, standard treatment	check	97.0	0.5	22.1	9.0
	Formalin, standard treatment	inoc.	38.5	1.7	98.8	77.8
	Formalin, double strength	check	99.0	—	4.5	2.1
	Formalin, double strength	inoc.	73.0	6.4	89.8	50.2
	Formalin, standard treatment for double time	check	99.0	—	7.0	2.4
	Formalin, standard treatment for double time	inoc.	91.0	2.4	96.2	35.3
	Formalin, 2 standard treatments	check	88.0	0.5	34.1	20.0
	Formalin, 2 standard treatments	inoc.	60.0	7.6	92.1	61.5

The results which are presented in Table 1 show that under greenhouse conditions, wheat seed which had been exposed to frost, rust, drought, sprouting conditions and formalin treatments had a poorer emergence than normal wheat. Moreover, the resulting seedlings were more susceptible to attack by *H. sativum* than those

TABLE 2.—*The emergence and yield from normal and injured wheat, inoculated with H. sativum and sown in rod rows at Saskatoon and Muenster, 1932. Twelve hundred seeds were sown in each of the 26 series.*

Variety of Wheat	Type of Seed	Series	Saskatoon		Muenster	
			Emergence %	Yield-grams per rod row	Emergence %	Yield-grams per rod row
Reward	Normal	check	79.0	199.0	76.5	124.0
	Normal	inoc.	67.5	182.5	60.0	119.0
	Frozen	check	57.5	141.0	55.0	122.5
	Frozen	inoc.	13.5	87.0	10.0	27.0
Marquis	Normal	check	91.5	233.0	85.5	181.0
	Normal	inoc.	78.5	246.0	78.5	170.0
	Shrivelled	check	81.5	204.0	70.5	156.0
	Shrivelled	inoc.	54.5	171.5	43.0	83.5
Marquis	Normal	check	96.5	265.5	88.5	212.0
	Normal	inoc.	86.0	229.0	84.5	181.0
	Sprouted	check	62.5	244.0	61.5	189.0
	Sprouted	inoc.	34.0	175.0	29.5	103.0
Reward	Normal	check	97.0	236.0	87.0	116.0
	Normal	inoc.	93.5	216.0	73.0	117.0
	Immature	check	53.0	150.0	38.0	72.0
	Immature	inoc.	27.0	101.0	11.5	25.0
Marquis	Normal	check	96.5	264.5	98.0	169.5
	Normal	inoc.	84.5	251.0	83.0	165.0
	Formalin, standard treatment	check	96.5	250.5	88.5	200.0
	Formalin, standard treatment	inoc.	68.0	249.0	54.0	99.0
	Formalin, double strength	check	85.5	234.0	84.5	168.0
	Formalin, double strength	inoc.	61.0	206.0	53.5	96.0
	Formalin, standard for double time	check	89.5	266.0	89.0	211.0
	Formalin, standard for double time	inoc.	75.5	232.0	72.5	159.0
	Formalin, 2 standard treatments	check	89.0	256.0	87.5	177.5
	Formalin, 2 standard treatments	inoc.	71.0	231.0	49.5	128.0

from normal seed. Marked reduction in emergence resulted from all types of injury except that of rust. It was the chief factor considered in calculating the disease ratings. Seedling blight was common among the seedlings which grew from the uninculated frozen, sprouted and immature seed checks. When the seed was inoculated, the number of blighted seedlings was much greater than when normal seed was inoculated.

Results of Field Experiments

Seed from the same samples that were used in the greenhouse studies was prepared for the field test, all of the treatments and inoculations being done at the same time. The Saskatoon plots were sown on May 6, and those at Muenster, Saskatchewan, on May 12. The seed was sown with a hand seeder regulated to sow exactly 200 seeds per row. The rows, on which emergence and yield notes were to be taken, were sown in plots of three, 8 inches apart and separated from the next plot by a buffer row. In addition the plots on the outer ends of the ranges were well protected by border rows. The emergence was counted three weeks after seeding. When the grain was nearly ripe, the heads were cut off, dried, threshed and weighed. The emergence and yield data from both places are presented in Table 2.

On the whole, the emergence was poorest at Muenster where the plots were sown almost a week later than at Saskatoon. This is in agreement with results of experiments with *H. sativum* carried on by McKinney (*5*) and at this laboratory, in which it has been determined that because of a more favourable soil temperature for the growth of the fungus later in the season, greater infection takes place. The results show that each type of seed which was used was affected similarly by the fungus at both places; that is, the seedlings from injured seed were more susceptible to the fungus than those from normal seed. Throughout the season the inoculated plants were retarded in their development in comparison with the check plants, particularly where the emergence was severely reduced, as with frozen, sprouted and immature seed. Considerable secondary growth and increased tillering occurred among these plants, resulting in lateness of growth and immature seed. When the results given in Table 2 are examined it is apparent that poor stands yielded comparatively well at Saskatoon due in part probably to increased tillering. However, this recovery did not occur at Muenster, except in a few rows.

Discussion and Conclusions

The four types of natural injury to wheat seed used in these experiments are largely the result of varied weather conditions. The immature seed was grown in a drought-stricken area; the frozen seed, in an area where late rains caused increased tillering with subsequent uneven ripening. Wet weather during the harvest season caused sprouting in head, stook and swath. In southeastern Saskatchewan, where the shrivelled seed was produced, rains at the critical season created conditions favourable to a severe rust epidemic in that locality. Because these adverse weather conditions may obtain in any year, it is to be expected that a portion of each year's crop will show these types of injury.

The fungus, *H. sativum*, which was used to inoculate the wheat seed in these greenhouse and field experiments, is one of the fungi causing severe root rot of wheat. Under the conditions of these experiments, naturally injured wheat seed gave a poorer emergence and yield than normal seed. When both kinds of seed were inoculated with the fungus, the emergence and yield from the injured seed were much poorer than those from normal seed. The results of the experiments show that losses as great as 70% in emergence and 60% in yield were sustained when frozen, sprouted and immature wheat seed were inoculated with *H. sativum* and sown late. Under the same conditions, reductions of about 15 and 12% in emergence and yield respectively resulted when normal seed was sown. Shrivelled

seed emerged and yielded quite well in the greenhouse and plots when the seed was not inoculated, but when it was inoculated, both emergence and yield were greatly reduced, as compared with inoculated normal wheat.

The results of other investigations and of these experiments indicate that ordinary formalin treatments may injure wheat seed but under the conditions of these experiments no greater injury resulted from doubling the strength, time or number of formalin treatments. The seedlings from all of the formalin-treated seed were more susceptible to *H. sativum* than those from normal seed which had been inoculated only.

Summary

1. Other investigators have shown that mechanical and other injury of wheat and barley renders the seed susceptible to attack by soil-inhabiting saprophytes and parasites.

2. Normal wheat seed and seed which had been injured by frost, rust, sprouting, drought and formalin was sown in the greenhouse and in plots, some of the seed being inoculated with *H. sativum*, the rest serving as checks.

3. Damage in the form of non-emergence and blighting was greater when injured seed was inoculated than when normal seed of the same variety was inoculated. Reductions in stand and yield occurred also when injured seed was sown without inoculation.

4. Since the fungus *H. sativum* is common in practically all soils within a few years after breaking and may cause considerable damage to wheat, the use of sound seed sown as early as possible is recommended.

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STUDIES ON THE EFFECT OF ENVIRONMENTAL FACTORS ON THE PENTOSAN CONTENT OF WHEAT PLANTS IN RELATION TO FOOT ROT[1]

L. E. Tyner[2]

The purpose of this study was to determine the rôle played by carbohydrate metabolism in the wheat plant in relation to disease expression as caused by the foot-rotting pathogens, *Ophiobolus graminis*, *Helminthosporium sativum*, and *Fusarium* spp. However, the immediate purpose was to examine the hypothesis that certain foot-rotting fungi exhibit preferences for the different carbohydrates of the wheat plant. Therefore, attention was given to the rôle of the pentosans and pentosan complexes found in wheat seedlings. Chemical analyses and microchemical tests were made in an effort to find a reliable quantitative measure of the pentosan content of plant tissues grown under various environmental conditions, since such measurements might be taken as indices of the response of the wheat plant to the foot-rotting pathogens under different environments. The necessity of investigating from this angle the reactions of the pathogens indicated was suggested by the work of Dickson and co-workers (*3*, *4*, *7*) at Wisconsin, who state that the pathogenicity of *Gibberella saubinettii* is stimulated in the tissues of wheat and corn plants when their metabolic equilibrium is unbalanced, and that a high percentage of pentosans in the plant goes hand-in-hand with such unbalanced state. The factor of high soil temperature was thought to be highly significant in causing this unbalanced metabolic condition in the wheat plant.

The present investigation was concerned mainly in studying the effects of light intensity, soil temperature, and soil moisture in inducing changes of the carbohydrate metabolism, and the extent and result of such changes in modifying the expression of the disease in the host. In addition, an effort was made to link up the growth responses of *H. sativum in vitro* with features of the carbohydrate organization in wheat seedlings, the tissues of which were used to supply the only carbon source for the growth of the fungus. Also, an effort is being made to determine whether the pentosan content of wheat seedlings, growing under conditions of excesses and of deficiencies of the common soil nutrient elements, is an important factor in the degree of disease expression.

Experiments and Results

The effect of illumination, soil temperature, soil moisture, and various fertilizers on the pentosan content of wheat seedlings

Illumination.—The experiments on the effects of illumination were carried out in the greenhouse and also in temperature control chambers set at suitable temperatures. Both natural sunlight and artificial illumination were used for the greenhouse work, and artificial light in the chambers. It was thought that the latter method, though not simulating field conditions, provided a more measurable state and made possible more accurate control of the constants, soil moisture and soil temperature. Various factors in relation to the degree of illumination received by the plants were determined, viz.: the extent and amount of lignification and of pentosan-bearing tissue, as demonstrated in stained free-hand sections; the pentosan percentages as determined by chemical analyses; the degree of infection of the plants by *O. graminis;* the value of plant extracts made from the dried plant material as food sources for the fungus *H. sativum in vitro*, and the vigour of the plants as determined by their total dry weight and average height.

[1] *Contribution from the Division of Botany, Experimental Farms Branch, Department of Agriculture, Ottawa, Canada, co-operating with the University of Alberta. This paper constitutes part of a thesis submitted April, 1933, to the University of Alberta, in partial fulfilment of the requirements for the degree of Master of Science.*

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Since the factor of light plays the dominant rôle in the processes of photosynthesis (*1, 11*), one would expect marked differences in the carbohydrate metabolism and possibly in the expression of disease. These expectations were realized. Thus, plants growing under curtailed illumination were lower in pentosan content, were more susceptible to attack by *O. graminis*, and were less vigorous as expressed by their average height and the total dry weight. The stained sections showed a much less extensive lignification of the tissues and a consequent decrease in the pentosan staining area. Some results from the infection studies appear in Table 1.

TABLE 1.—*A comparison of average height and infection ratings of Marquis wheat seedlings grown under different intensities of illumination in sterilized soil infested with Ophiobolus graminis.*

Treatment		Plants number	Height cm.	Infection rating %	Soil temperature range °C.
(Experiment A*)					
Natural light—	Inoculated	511	31.3	36.3	From 16.5–21
	Control	98	37.5	0.6	
Subdued natural light—	Inoculated	527	27.1	61.1	From 15–20
	Control	97	35.1	1.44	
(Experiment B†)					
400 watts—	Inoculated	378	26.6	56.14	From 17–20
	Control‡	88	35.5	0.70	
100 watts—	Inoculated	428	25.0	65.64	From 14-17
	Control	101	29.0	0.40	

*Greenhouse conditions, January, February.
†Artificial light only, in control chamber.
‡Slight infection due to chance contamination with other fungi.

Soil Temperature.—The experiments on the effect of temperature were carried out in the constant temperature control tanks of the Field Crops Department, University of Alberta. The temperature of the soil was adjusted to a range of four values of approximately 16°, 21°, 26° and 31° C. Here the air temperature was that of the greenhouse, approximately 20° C. Material grown during summer, and also during winter, was studied. No attempt was made to study disease expression in relation to temperature, as this has been fully studied by others. Only such factors as the histological observation of pentosans, their quantitative estimation, and the vigour of the plant, were recorded. No definite quantitative differences in the pentosan percentages of plants grown at the above temperatures were noted. The tests were not very extensive, however, and might well be repeated, particularly as the air temperature, and soil temperatures, were different. This inconsistency might be influential in view of the fact that the total plant tissue was used in the analyses in this experiment.

There were marked differences observed in the extent of lignification, and in the amount of pentosan staining tissue, in sections from the roots of plants grown at the different temperatures, the most marked staining reaction and lignin deposition being observed in the material grown at 26° C. Thus, it would seem that, contrasting the quantitative estimation with the histological examination, discrepancies exist between the two methods of measurement. It is suggested that the

hydrolysable sugars in solution in the protoplasm of the plant cells play an important part, their effects being masked in one method of examination and apparent in the other.

Considering the work of Dosdall (*5*), Henry (*6*), McKinney and Davis (*9*), and others who have observed the damage from the foot rot pathogens under different temperatures, it must be admitted that somewhat definite temperature optima exist for the various fungi. Since extremes in soil temperature may be expected to be directly linked with extremes of soil moisture and illumination under field conditions, it is difficult to decide just what significance to attach to soil temperature alone. Jones, Johnson and Dickson (*7*) have ascribed considerable importance to this factor under controlled conditions, showing that it is associated with marked differences in the degree of infection of wheat seedlings by *G. saubinetii*. The following is a quotation from their work:— "At temperatures above 20° C., the growing point of the plumule always pushed through the coleoptile before emerging from the soil. At temperatures below 16° C., however, the coleoptile elongated very much faster than the growing point of the plumule and as a result inclosed the embryonic tissues until after emergence, thus preventing the growing tip from direct contact with the soil and soil-inhabiting organisms". Dickson (*3*) and Dickson and Holbert (*4*) observed definite differences in the composition of cell walls and in the stability of the complexes by qualitative microchemical tests, but observed little difference by quantitative analysis for the hydrolysable sugars, in the composition of plants grown at temperatures ranging from 12° to 24° C.

Soil Moisture.—For this study the moisture content of sterilized soil was adjusted to 70, 60 and 45% of its moisture-holding capacity. Seed of Marquis wheat was planted in each moisture series and *O. graminis* was not introduced. The illumination was natural light under greenhouse conditions during January and February. After 30 days the seedlings (including roots) were removed from the soil, the average height and dry weight obtained to indicate vigour, and later analyses were made for pentosan content. The results are given in Table 2. The pentosan content of the tissue varied inversely with the moisture content of the soil. It appears that the lower the weight per plant, the greater is the pentosan content.

TABLE 2.—*Dry weights, and results of pentosan analyses of Marquis wheat seedlings, grown in soils of different moisture content.*

Approximate moisture-holding capacity %	Average dry weight per plant gm.	Weight of precipitate phloroglucide in duplicates gm.	Pentosan %	Total number plants
70	.096	.0768	4.85	233
		.0790	4.98	
60	.077	.0962	5.99	272
		.0880	5.51	
45	.060	.1210	7.46	231
		.1192	7.35	

If, as McKinney and Davis (*9*) state, the infection of wheat by *O. graminis* is more severe in soils of high moisture content, and according to the present studies the pentosan content is lower in moist soils, it might be considered that low pentosan content and increased susceptibility are closely related. This relation also appeared in the case of the studies on illumination, where the plants receiving less light had

less pentosans and were more susceptible to disease. Hence, it must be concluded, that, aside from offering favourable and easily utilizable sources of food for the fungi, the pentosan content quantitatively is but indicative of the general vigour of the host. Thus, any resistance noted in seedlings grown under particular environmental conditions is only indirectly related to the pentosan content, and directly related to the plant vigour, of which the extent of carbohydrate metabolism is an expression. This contention is borne out by the results of a test in which three representative wheat varieties were analyzed for pentosans. It was found that the variety which appeared to be most resistant in the field also yielded the highest percentage of pentosans. Again, when *H. sativum* was cultured in liquid media, containing, as the only carbon source, the extract from dried wheat seedlings grown under differing intensities of illumination, the extract from the most vigorous plants and, moreover, with the greatest sugar content, supported the most abundant growth of mycelium.

Obviously any experiment designed to test the reactions of a fungus to various nutrients is complicated by a consideration of the enzymatic complement of the fungus. On this account a sweeping generalization cannot be made regarding the suitability of a specific carbohydrate as food. Thus, it may be that fungi possessing alike or similar complements of enzymes would show similar pathogenic habits in the same plant variety.

Fertilizers.—The effect of excess or deficiency of mineral nutrients, added to the substratum, on the pentosan content of wheat seedlings, is now being studied, and, although only preliminary results are yet available, indications are that differences in the pentosan content of Marquis wheat seedlings vary over a fairly narrow range. However, the small but apparently significant differences suggest that the investigation holds promise of interesting correlations between the various fertilizers and the carbohydrate complex of the treated plants. It appears that a low weight per plant is associated with a high pentosan percentage per plant. This means that those plants lacking in verdant growth, due to nutrient deficiencies, or to the influence of the organism when infested soil is used, or to both influences, contain more lignin and pentosan-bearing tissues per unit mass than do the more succulent plants.

Summary

The object of this investigation was to determine what relation the pentosan content of wheat seedlings might have to their infection by *O. graminis*, *H. sativum* and *Fusarium* spp. and to utilize this knowledge in connection with securing greater natural resistance in varieties. The pentosan content was studied by staining the root tissue, and by quantitative chemical analysis of the complete plants. The plant material was grown under different degrees of light, temperature and soil moisture.

The microchemical tests indicated that the lignification of the tissue, and consequently the pentosan staining area, was reduced by curtailed light, and definitely increased by greater light intensities. Under a temperature centering around 25° C., and greenhouse illumination during the winter months, the pentosan staining area was extended, while it was reduced at a temperature of 16° C., at the same illumination.

According to the quantitative chemical tests, plants grown under higher illuminations were definitely higher in pentosan content, and were more vigorous with greater dry weight than those grown under lower light intensities. A temperature range of 16° to 31° C., apparently did not affect the pentosan content of seedlings grown under the higher light intensity. There was an inverse variation in pentosan content of seedlings from soils held at 70, 60 and 45% of the moisture-holding capacity. Indications are that the carbohydrate complex of the wheat plant is closely related to its morphological characters and vigour, but the exact relation of either of these with natural resistance requires further study.

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STUDIES ON FOOT AND ROOT ROT OF WHEAT

III. Effect of Crop Rotation and Cultural Practice on the Development of Foot Rot of Wheat[1]

W. C. Broadfoot[2]

(abstract)[3]

Although certain investigators in Australia, Europe, the United States of America, and Canada have recommended various crop rotations and cultural practices to reduce some of the foot rots, it is felt that, as often only one disease is concerned, such recommendations may not be applicable to the situation in Western Canada, or to the foot rot complex as a whole as it develops naturally in a crop sequence during several years. Consequently, this laboratory initiated, with the co-operation of the five Dominion Experimental Stations located at Morden, Manitoba; Indian Head, Swift Current and Scott, Saskatchewan; and Lethbridge, Alberta; the two Alberta Schools of Agriculture, at Olds and Vermilion, from 1928 to 1932, inclusive (a total of 28 station years), an intensive and uniform crop rotation project, where the development of the foot rot complex might be studied naturally under a wide range of soil and climatic conditions. Foot-rotting fungi were not added to the soil, or their development unnaturally stimulated. Also, the crop sequence and tillage methods were carried out in a way quite comparable to ordinary farming methods.

[1] *Contribution from the Division of Botany, Experimental Farms Branch, Department of Agriculture, Ottawa, Canada, co-operating with the Dominion Experimental Farms at Morden in Manitoba, Indian Head, Swift Current and Scott, in Saskatchewan, and at Lethbridge in Alberta, and the Alberta Schools of Agriculture at Olds and Vermilion. This paper constitutes one part of a thesis submitted May 3, 1932, to the graduate faculty of the University of Minnesota in partial fulfilment of the requirements for the degree of Doctor of Philosophy.*

[2] *Plant Pathologist, Dominion Laboratory of Plant Pathology, Edmonton, Alta., Canada.*

[3] *The complete paper appears in Canadian Journal of Research: 10 (1): 95-114, 1934.*

The development of the foot rot complex was studied on wheat in two-year rotations where wheat alternated with summer-fallow, oats, and barley; in three-year rotations where it followed two years of summer-fallow, oats, sweet clover, western rye grass, one year of summer-fallow, and also as the first and second wheat crop after a manured and non-manured summer-fallow; in a six-year rotation where it followed summer-fallow, and after two years of western rye grass. It was also studied on wheat under various cultural practices, as the first and second wheat crop after summer-fallow. In this part of the experiment, the date, depth, and rate of seeding wheat were each varied three ways, that is to say, the seed was sown early, average, and late; deep, average, and shallow; and at light, average, and heavy rate. Also, the effect of packing and no packing of the soil was studied.

Field notes were taken just before the plants were wholly mature. Twenty plants were chosen at random from each of four replicates of 1-100 acre plots each, representing each rotation or practice. The crowns and sub-crowns were cut longitudinally, and the secondary roots examined and rated numerically for degree of infection. An adequate, representative sample of the basal portion of the plants from each plot was brought to the laboratory and the isolations made therefrom are reported in Part IV of the general subject of this study. Yield was taken at most of the stations.

The relation between the actual degree of injury to the crown tissue and the colour of the tissue, or its relation to the degree of shrivelling of the grains was studied. Thus, in spite of the fact that certain cases arise where the relation might be fairly close, the actual conditition of the crown and root tissue is not always reflected by the colour of this tissue or by the soundness of the spike. The same may be said regarding yield. Consequently, the infection rating was based wholly on the condition of the crown and secondary roots. These data were further supplemented by the number of fertile culms, total culms, and yield.

It was found that the agreement in results among replicates of a given treatment, as well as the means of two similar sequences, at the various stations, was reasonably satisfactory, under the conditions of the experiment.

It was found that foot rot damage of wheat is significantly reduced where wheat alternates with summer-fallow in a two-year rotation; where it follows summer-fallow in other rotations; alternates with oats in a two-year rotation, follows oats in a three-year rotation, follows sweet clover in a three-year rotation, or where wheat is sown late. It is increased where wheat follows wheat, barley, or western rye grass. This study does not refer to foot rot caused by Pythium spp.

STUDIES ON FOOT AND ROOT ROT OF WHEAT

IV. Effect of Crop Rotation and Cultural Practice on the Relative Prevalence of *Helminthosporium sativum* and *Fusarium* spp. as Indicated by Isolations from Wheat Plants[1]

W. C. Broadfoot[2]

(abstract)[3]

Either *Helminthosporium sativum* or Fusaria or both are generally isolated from the crowns and other basal parts of wheat plants suffering from foot rot, and yet they may or may not be saprophytic. Ordinarily, these fungi, when the tissue is

[1] *Contribution from the Division of Botany, Experimental Farms Branch, Department of Agriculture, Ottawa, Canada, co-operating with the University of Alberta. This paper constitutes one part of a thesis submitted May 3, 1932, to the graduate faculty of the University of Minnesota in partial fulfilment of the requirements for the degree of Doctor of Philosophy.*

[2] *Plant Pathologist, Dominion Laboratory of Plant Pathology, Edmonton, Alta., Canada.*

[3] *The complete paper appears in Canadian Journal of Research: 10 (1): 115-124, 1934*

surface-disinfected and incubated on solid media, grow to the exclusion of *Ophiobolus graminis*, even when the latter has caused most of the damage. On the other hand, *H. sativum* and *Fusarium* spp. are important foot-rotting pathogens, and they are extremely common in the soils of Western Canada. However, there appear to be no very definite results in the literature whether the relative proportion of these are modified by certain crop rotations, cultural practices, regional location, climatic, or other factors. Opportunity to obtain information on these interesting possibilities was afforded by the material available in the crop sequence and cultural studies mentioned in Part III of the general subject of this paper.

In spite of certain variations, it seemed best, and reasonably safe, for the purposes of this study, to culture from the crown tissue only. Routine procedure was to take the main tiller, remove the secondary roots close to the crown, the sub-crown internode about 1 cm. below it, also the culm about 1 cm. above the crown. An adequate representative sample of wheat plants from each of the four replicates of the various crop rotations and cultural practices were incubated on potato sucrose agar in petri plates, after surface-disinfecting in a 1:1000 mercuric chloride solution for two minutes.

Of the 47,360 plants analyzed in this study, the crown and root tissue from 43,305 plants yielded *H. sativum*, *F. culmorum* and *Fusarium* spp., either alone or in combination with these and other identified and unidentified fungi and bacteria, so that it may be safely said that it was the exception for any mature plant, the surface tissue of which was treated, to be free from fungi or bacteria. *H. sativum* and Fusaria were usually always isolated from plants, the basal tissue of which bore signs of foot rot infection. Sometimes one or more of the following grew from the tissue: *H. sativum*, Fusaria, Penicillia, *Alternaria*, *Rhizoctonia* sp., *Macrosporium* sp., Cladosporia, *Actinomyces* sp., *Hormodendrum* sp., *Wojnowicia graminis*, *Ascochyta graminicola*. *Aspergillus niger* and *Monilia sitophila* frequently grew from the plated tissue, and often to the exclusion of other fungi and bacteria. However, in most cases, the tissue yielded either *H. sativum* or Fusaria, or both. In spite of the fact that signs of attack were evident on occasional wheat plants in all experiments, and at certain stations were more or less pronounced, *O. graminis* was not definitely identified. Its absence may be accounted for partly by the presence of other stronger-growing micro-organisms in plate culture, by the rather unsuitable substrate that was used, by the slow growth habit of this fungus, or by the disinfectant used.

As far as could be ascertained by this study, the crop sequence or cultural practice used did not appear to significantly affect the relative prevalence of either *H. sativum* or Fusaria. This is interesting, in view of the fact that summer-fallow, a crop of oats, sweet clover, or some non-susceptible crop, actually reduces foot rot damage on the following crop of spring wheat.

Perhaps the most significant of the results obtained was the indication that the climatic conditions, and possibly the soil, at a station each year determined the relative prevalence of *H. sativum* and the Fusaria, in the crown tissue of wheat plants.

ON VARIETAL RESISTANCE OF *MEDICAGO* AND *MELILOTUS* TO ROOT ROTS CAUSED BY *SCLEROTINIA* SP. AND *PLENODOMUS MELILOTI* D. & S.[1]

G. B. Sanford and M. W. Cormack[2]

The increasing cultivation of *Medicago* (alfalfa) and *Melilotus* (sweet clover) in Western Canada has emphasized the importance of the root rots of these crops. Winter injury is still important, but much of the damage formerly attributed to winter killing is now known to be caused by the root-rotting pathogens *Sclerotinia* sp. and *Plenodomus meliloti*. The studies of Sanford (*1*) and Sanford and Cormack (*2*) have indicated the economic importance of these pathogens.

As the most satisfactory solution for this root rot problem would be the development of varieties possessing natural resistance, a study of the reaction of the commonly grown and promising varieties of alfalfa and sweet clover to *Sclerotinia* sp. and *P. meliloti* was begun in 1928, and is being continued at the present time. While the results reported here are preliminary, certain interesting trends have been observed, which may give some indication of the value of the different species and varieties to the plant breeder.

Material and Methods

LOCATION AND PLAN OF EXPERIMENTS

A large number of varieties of alfalfa, sweet and common clover have been tested during the past four years. However, many of these have been discontinued on account of not being winter-hardy, or for other reasons. The results from varieties of *Trifolium* are not given in this paper.

The tests were made under field conditions, one experiment being located at the University of Alberta, Edmonton, and its duplicate at the Dominion Experimental Station, Lacombe, Alberta, about 85 miles south of Edmonton. At each location, a permanent area was divided into several ranges, each five feet wide, and separated by a two-foot path. Each range, of equal dimensions, was long enough to allow of planting all varieties tested, in rows 1½ feet apart. Thus, there were available two ranges, the soil of which was artificially infested with *Sclerotinia* sp., and two ranges with *P. meliloti*. Between each infested range was a check range. Across the various ranges were seeded in rows, as indicated, during late June, the varieties of *Medicago* and *Melilotus*. Only hand tillage was employed. By the arrangement described, comparable conditions were obtained, and due regard given to distribution of soil differences.

METHODS OF INOCULATION

Pure cultures of *Sclerotinia* sp. (probably *S. sclerotiorum*) and of *P. meliloti*, of known virulence to both alfalfa and sweet clover, were used in all experiments. These cultures were isolated from the diseased roots of sweet clover. During preliminary studies (1928-29), several methods of inoculation were tried. At first, in late autumn, just before the ground froze, inoculum, grown on nutrient agar, was inserted into cavities punched in the tap root, by means of a cork borer. Another method was to place against the tap root, inoculum grown on ground oat hulls. It was found, however, that the infection, obtained by these methods, was generally so severe, that it was difficult to distinguish any significant differences in resistance among varieties (Figure 1, A.). Consequently, in 1931, we added to the field soil, at seeding time, inoculum, which was grown in sterilized soil plus 5% by volume of cornmeal. Unfortunately, while this method gave very satisfactory results with

[1] *A contribution from the Division of Botany, Experimental Farms Branch, Department of Agriculture, Ottawa, Canada, co-operating with the University of Alberta.*

[2] *Plant Pathologist in Charge and Assistant Plant Pathologist, respectively, Dominion Laboratory of Plant Pathology, Edmonton, Alta., Canada.*

Sclerotinia sp. it appeared to be ineffective for some reason, for *P. meliloti.* In applying the inoculum to the soil, about 1 pint of it was distributed in a narrow furrow. After this had been thoroughly mixed through the soil, the row was again marked directly above, and the seed sown.

The extent of root rot damage was observed after growth had started, early in May of the following year. The plants were dug up and the roots examined, and numerical values from zero to ten given to indicate the degree of infection. In this paper, only yearly averages are given, and these are based on a total of 80 plants of each variety, 40 of which were grown at Edmonton and 40 at Lacombe.

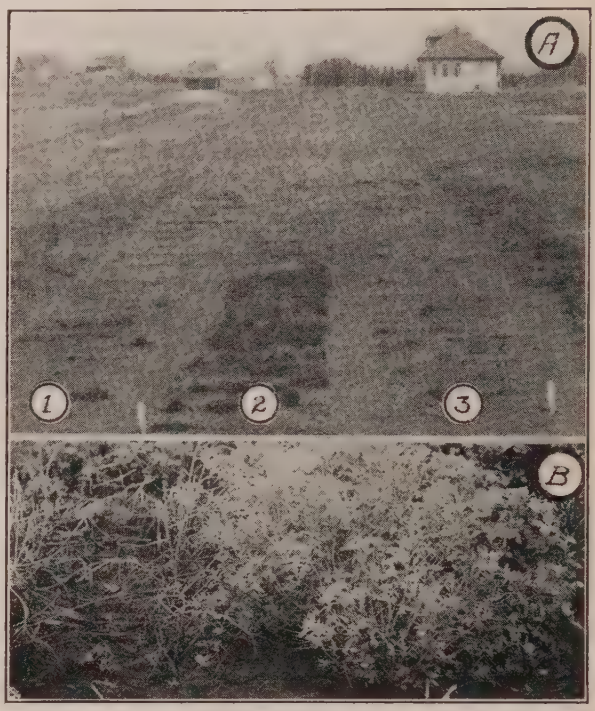

FIGURE 1. *A. Three ranges at Edmonton each containing the same varieties of Medicago and Melilotus: (1) inoculated with Plenodomus meliloti; (2) control; (3) with Sclerotinia sp. Note extensive killing in ranges 1 and 3, and healthy condition of plants in range 2. Photographed May, 1931.*

B. Left, (dead) Arctic sweet clover; right, Grimm Alfalfa. The soil of these rows was similarly infested with Sclerotinia sp. when the seed was planted. Note relative susceptibility. Photographed May, 1932.

EXPERIMENTAL RESULTS

REACTION OF VARIETIES OF *Medicago* TO *Sclerotinia* SP.

The reaction of representative varieties of alfalfa to *Sclerotinia* is indicated by the values given in Table 1. These results suggest that all varieties of alfalfa were relatively resistant to the attack of the strain of *Sclerotinia* sp. used. The plants were seldom seriously injured, and, in most cases, the pathogen only caused slight surface lesioning of the tap roots. However, there were consistent differences in varietal reaction, which appear to be significant. The yellow-flowered *Medicago falcata* showed a high degree of natural resistance and was in all cases less susceptible than other varieties tested. As plants of this variety have a

TABLE 1.—*Reaction of varieties of Medicago to Sclerotinia sp.*

Variety	Yearly average rating		Average	Variety	Yearly average rating		Average
	1931-32	1932-33			1931-32	1932-33	
Medicago falcata	0.1	0.1	0.1	Grimm	0.8	1.3	1.0
Wisconsin No. 892	0.6	0.8	0.7	Hardistan	1.5	1.5	1.5
Cossack	0.7	1.1	0.9	Liscombe	1.2	2.1	1.6
Baltic	0.5	1.3	0.9	Provence	2.8	2.4	2.6
Ontario Variegated	0.2	1.7	0.9				

very slender growth, and can be cut only once during a season, it is not suitable for general use as a hay crop, but it might offer possibilities as plant breeding material for greater resistance. The varieties Hardistan, Liscombe and Provence were consistently more susceptible to *Sclerotinia* sp. They were also the least winter-hardy of the varieties tested.

REACTION OF VARIETIES OF *Melilotus* TO *Sclerotinia* SP.

In these studies sweet clover was markedly more susceptible than alfalfa to the attack of *Sclerotinia* sp. (Figure 1, B.). The infection values of representative sweet clover varieties are given in Table 2, where consistent and sometimes marked differences in varietal susceptibility are indicated.

Varieties of *Melilotus officinalis*, viz. Yellow Blossom, Albotrea and Zouave, were the most resistant to *Sclerotinia* sp. of all varieties tested. This was indicated

TABLE 2.—*Reaction of varieties of Melilotus to Sclerotinia sp.*

Variety	Yearly average rating		Average	Variety	Yearly average rating		Average
	1931-32	1932-33			1931-32	1932-33	
Yellow Blossom	3.7	5.1	4.4	White Blossom	4.9	8.6	6.7
Albotrea	3.8	6.5	5.1	Arctic	5.2	9.1	7.1
Zouave	3.3	6.9	5.1	Fansher	5.5	8.8	7.1
Grundy County	4.8	6.2	5.5	Alpha No. 2	5.3	9.8	7.5
Early Dwarf	4.8	7.5	6.1	Maccor	6.2	9.3	7.7
Alpha No. 3	3.6	9.2	6.4	Alpha No. 1	5.7	10.0	7.8

TABLE 3.—*Average infection ratings of varieties of Medicago and Melilotus, non-inoculated and inoculated with Plenodomus meliloti, 1932 and 1933.*

Variety	Control	Inoculated	Variety	Control	Inoculated
Medicago			*Melilotus*		
Medicago falcata	0.05	0.05	White Blossom	0.5	0.6
Ontario Variegated	0.3	0.1	Arctic	1.1	0.6
Grimm	0.3	0.3	Yellow Blossom	0.8	0.6
Cossack	0.3	0.3	Albotrea	1.0	0.9
Wisconsin No. 892	0.4	0.4	Grundy County	0.8	0.9
Baltic	0.5	0.4	Fansher	0.9	1.0
Hardistan	0.4	0.6	Alpha No. 3	1.0	1.0
Liscombe	1.0	0.6	Alpha No. 2	1.1	1.1
Provence	0.9	1.0	Zouave	1.4	1.2
			Early Dwarf	1.2	1.3
			Alpha No. 1	1.3	1.5
			Maccor	1.7	1.8

by a consistently lower percentage of dead plants, and less severe root damage of surviving plants. Two white-blossomed varieties, viz. Grundy County and Early Dwarf, were also less susceptible, but all other varieties of *M. alba* were very severely attacked. Maccor and two of the dwarf hybrid Alpha strains proved to be most susceptible in these tests.

REACTION OF VARIETIES OF *Medicago* AND *Melilotus* TO *P. meliloti*

The results obtained with *P. meliloti* were rather inconclusive, owing to difficulties experienced in securing an effective infestation of the soil. When the inoculum was placed against the roots late in autumn the rotting was too severe, but when it was placed in the soil at seeding time the pathogen lost its effectiveness during the remainder of the season and did not attack the roots the following spring. It will be recalled that, with this method, the inoculum of *Sclerotinia* sp. was still very effective. Light infection, however, was obtained, but this was seldom any more severe than that in the non-inoculated check rows. The data presented in Table 3 show the close agreement in this respect, and also indicate the relative susceptibility of different varieties of alfalfa and sweet clover obtained under the conditions.

Discussion and Summary

One of the most interesting results of the foregoing experiments is that, in general, varieties of both alfalfa and sweet clover are distinctly more susceptible to *Sclerotinia* and *P. meliloti* immediately following the period of winter dormancy than during the summer. Another result is that alfalfa is much more resistant than sweet clover to the culture of *Sclerotinia* used, either following winter dormancy or during the summer. Another feature of the study is that the effectiveness of the inoculum of *Sclerotinia* was maintained a year after it was added to the soil, whereas it was apparently lost in the case of *P. meliloti*. This happened two years in succession, but we are unable to give the reason.

Regarding varietal differences and natural resistance to the two pathogens mentioned, the data in Tables 1 and 2 indicate quite clearly that certain varieties of alfalfa and sweet clover are more resistant than others to *Sclerotinia*. This was particularly noticeable in the case of sweet clover, and less definite with alfalfa, although *Medicago falcata* seemed to possess marked resistance each year. On the other hand, varieties of sweet clover belonging to the *Melilotus officinalis* group were less susceptible than those belonging to the *M. alba* group. Maccor and the two strains of Alpha were very susceptible. Should the results obtained thus far be confirmed by subsequent tests, which will be continued for some time, it is hoped that information of definite value will be available for plant breeding purposes. The results were not conclusive with alfalfa and sweet clover in connection with *P. meliloti*, because a satisfactorily effective method of infesting the soil was not obtained.

Evidence obtained from these studies also indicates that winter hardiness and natural resistance are closely related in both alfalfa and sweet clover, at least in so far as the winter dormancy period is concerned. However, it is not clear what constitutes winter-hardiness in these legumes, or what changes occur in the plants during the winter, or what factors of the environment are effective in breaking down the natural resistance which clearly exists before the plants enter the winter dormancy period. It is also obscure why certain young and apparently normal plants of a variety are distinctly less resistant than others under field conditions.

Acknowledgment

We desire to mention our gratitude to Messrs. F. H. Reed and G. E. DeLong for excellent co-operation supplied by the Dominion Experimental Station, Lacombe, Alberta.

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TOXIN FORMATION BY SPECIES OF *PYTHIUM* PARASITIC ON WHEAT[1]

T. C. VANTERPOOL[2]

INTRODUCTION

An answer to the problem of whether or not a plant parasite produces metabolic products which are toxic to its host is of fundamental importance in understanding thoroughly the host-parasite relationship and the incidence of the disease under a given set of conditions. Information of this nature might help to explain the close correlation of browning root rot of cereals, caused primarily by *Pythium arrhenomanes* var. *canadensis* and other species of *Pythium*, with seasonal factors, cultivation practices and crop sequence. Furthermore, if a toxin is produced, the question of its formation on all or only on specific media would have to be elucidated in order to determine the nature of the culture medium on which the fungus may be grown for soil inoculation purposes in studies on parasitism. The present communication reports the results of investigations conducted in an attempt to throw light on the two points outlined above.

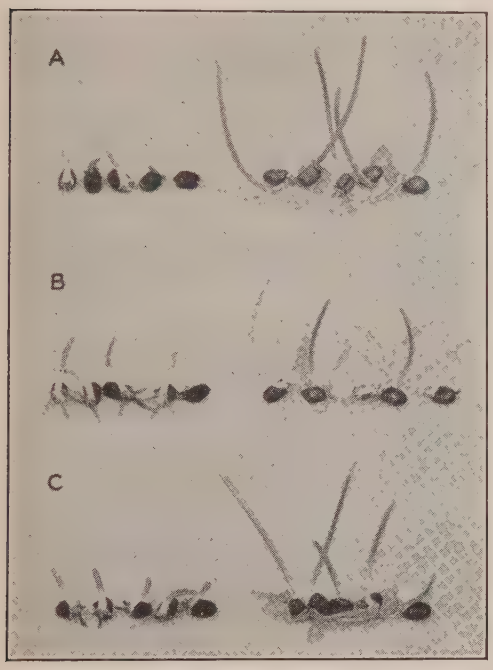

FIGURE 1. *Effect of toxins of P. arrhenomanes var. canadensis produced on oat-barley medium on the germination of wheat. The grains on the left were germinated in 20-day old culture extract; those on the right in extract of the medium. A, effect of extracts after centrifuging and filtering; B, after boiling; and, C, after passage through a 10-cm. soil column.*

GENERAL METHODS

The fungi were cultured on solid and liquid media for periods up to one month in the majority of cases. The solid media consisted of wheat grains, a mixture of oat and barley grains, rice, or a sand-cornmeal mixture containing 15% cornmeal. The liquid cultures were oat-barley, carrot-cornmeal, or cornmeal decoctions. Macerated water extracts of the cultures on solid media were centrifuged and filtered, and extracts of the media alone used as control. Filtrates of the liquid cultures were used, with the original liquid media as control. To test for the presence of a toxic principle, five disinfected Marquis wheat grains were germinated on filter paper wetted with 5 cc. of a given liquid in a sterile 125 cc. Erlenmeyer flask. All flasks were then placed on a laboratory table and after four days were examined for germination and growth of the seedlings. Unless otherwise stated, *P. arrhenomanes* var. *canadensis* was the fungus used.

EXPERIMENTAL

1. The relation of toxin formation to substratum.—P. arrhenomanes var. *canadensis* and other species of *Pythium* commonly associated with browning root rot of cereals

[1] *Contribution from the Laboratory of Plant Pathology, University of Saskatchewan, with financial assistance from the Saskatchewan Agricultural Research Foundation.*

[2] *Professor of Plant Pathology, Department of Biology, University of Saskatchewan, Saskatoon, Sask., Canada.*

when cultured on wheat grain, or on a mixture of oat and barley grain, produce a substance or substances which inhibit or prevent the germination of wheat and other cereals and cause a pronounced blackening of the grain (Figure 1, A). In the more dilute concentrations of the toxin where germination may be only inhibited, the growth of the primary roots is affected more than the pumule relative to control plants.

When cultured on rice medium, sand-cornmeal medium, or an oat-barley, carrot-cornmeal or cornmeal decoction, the presence of a toxin could not be established. Slight retardation was sometimes observed, but this may possibly have been due to bacterial contamination, especially in the rice-culture extract. The production of the toxin is, therefore, dependent on the nature of the substratum. Furthermore, as it is obtainable from an oat-barley grain culture and not from an oat-barley decoction culture (decoction prepared by extraction for one hour at 60° to 70° C.), it seems that the substance necessary for toxin formation is not water soluble.

FIGURE 2. *Discoloration of wheat grain produced by toxins of P. arrhenomanes var. canadensis. A, after 24 hours contact with filter paper moistened with toxic extract; B, after 24 hours contact with filter paper moistened with medium extract only. Darkening confined to pericarp and testa.*

Pre-soaking grain in toxic extract for about one hour usually has little or no effect on germination; but prolonged soaking for twenty-four hours or more ordinarily retards germination and may prevent it in some instances.

2. Effect of heat on the toxin.—Ordinarily the toxin is not affected by boiling or by autoclaving for 15 minutes at 15 lb. pressure, though occasionally its deleterious action on germinating wheat may be slightly decreased (Figure 1, B).

3. Effect of filtration through soil on the toxin.—Macerated culture extract was passed through a 10-cm. column of loamy soil contained in a glass tube 15 mm. in diameter. Tests for toxicity in the manner previously described showed that the soil had failed to adsorb the toxin (Figure 1, C). When, however, toxic extract is added to potted soil containing germinating wheat, there is an early retardation of 3 to 6 cm. in the growth of the seedlings compared with control plants receiving medium extract only. Later, however, this retardation disappears. Thus, in part at least, the soil is able to remove the toxin.

4. Effect of culture extract on the growth of the fungus itself.—Culture extracts in concentrations quite toxic to wheat germination, when added at full strength, diluted one-half, and diluted one-fifth with distilled water, at the rate of 5 cc. to each Petri plate of cornmeal, carrot-cornmeal or potato dextrose agar, failed to inhibit the growth of the fungus itself cultured thereon. In some instances an increase in radial growth was perceptible. It is possible that the agar may have rendered the toxin ineffective.

5. Effect of mycelial extracts on wheat germination.—Mycelial extracts from oat-barley and from carrot-cornmeal decoction cultures up to one month showed no definite toxicity to wheat. Mycelial extracts of three-month old cultures, especially those from oat-barley decoction, retarded primary root elongation slightly, but the discoloration of the grain, so characteristic of the oat-barley grain culture extract, was not produced. These results are probably due to different products of the fungus metabolism.

6. Effect of the toxin on root tissue.—Wheat seedlings with plumules and primary roots about 3 to 5 cm. long when transferred to the toxic extract usually cease growing and wilt. The action of the extract on excised root tips was also studied. From microscopic examination of the root cells it appears that the toxin is directly poisonous to the cells. No sign of dissolution of the cell walls is apparent. The fact that the presence of pectinase in the extract or filtrate could not be determined by its ability to soften thin carrot discs (cf. 5) might help to explain the absence of cell wall disintegration of the roots.

7. Effect of toxin on tomato plants.—Young tomato plants when cut under water and then placed with their cut ends in culture extract, wilt readily after several hours compared with controls in the medium extract only, which showed little effect on the second day.

8. Toxin production by other fungi on solid media.—Preliminary tests show that *Ophiobolus graminis* when cultured on oat-barley medium is capable of producing a toxin or toxins whose effects on germinating wheat are macroscopically indistinguishable from those of *P. arrhenomanes* var *canadensis* (Figure 3, A). Under similar conditions *Helminthosporium sativum* and *Fusarium culmorum* cause a slight retardation of the plumules and a moderate shortening of the roots, while only a faint, diffuse discoloration of the grain occurs. The toxin of *H. sativum* is slightly more inhibitory than that of *F. culmorum*. *H. sativum* produces the toxic substance on wheat grain medium more readily than on the oat-barley mixture. On the other hand, extracts of one-month-old cultures of *O. graminis* and *H. sativum* on crushed oat hulls medium showed no signs of similar toxicity. This suggests that with these two fungi also some specific substance seems necessary for the production of the toxic principle.

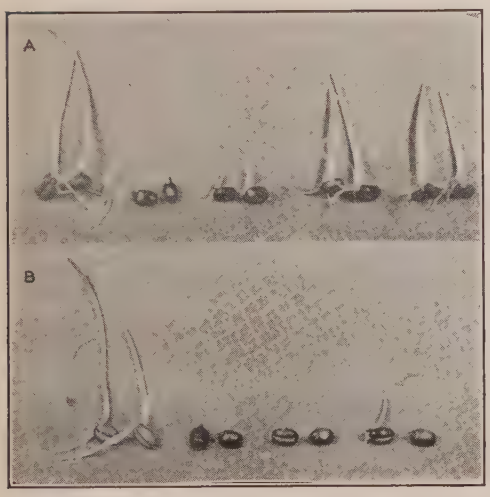

FIGURE 3. *Effects of excretory metabolic products of various parasites on wheat germination. A, left to right, extracts of oat-barley medium, P. arrhenomanes var. canadensis, O. graminis, H. sativum and F. culmorum, respectively. B, left to right, extracts of medium, P. arrhenomanes var. canadensis, P. ultimum, and P. debaryanum, respectively.*

P. debaryanum and *P. ultimum*, which are slightly or not at all parasitic on wheat, when cultured on oat-barley grains also readily produce a toxic substance whose effects on wheat are similar to those of the toxin of *P. arrhenomanes* var. *canadensis* (Figure 3, B). The ability to produce a substance toxic to wheat is not necessarily confined to parasitic fungi (cf. 4 and 5).

DISCUSSION

The toxic action of excretory and metabolic products of a *Pythium* sp. upon the germination of wheat has previously been reported by De Paolis (*1*). In the abstract available, no mention is made of the blackening of the wheat grain which is so characteristic of the extract from oat-barley and wheat cultures of *P. arrhenomanes* var. *canadensis*. He considers that the retardation of germination and early development of wheat produced by the toxins favours attack by *Pythium* itself as well as by other weak parasites. Our findings tend to substantiate this, but it is likely that the retardation produced by toxins of non-parasitic forms of *Pythium* and other soil-inhabiting saprophytes, also favours attack of the host by weak and

strong parasites. This gives some clue to the possible interrelations of the numerous saprophytic, weakly parasitic and strongly parasitic forms of *Pythium* which have been isolated from necrotic roots of wheat plants showing browning root rot symptoms. That excretory products of certain saprophytes are toxic to wheat has been shown by Scaramella (*5*) and by Mannozzi Torini (*4*). This latter author places the fungi tested into three groups depending on the effects of their products of excretion. Findings reported in this paper and by Kurosawa (*3*) and Shaffnit and Lüdtke (*6*) show that the production of toxins by fungi may be dependent on specific substances in the substratum. It is therefore probable that Mannozzi Torini's groupings hold good only for the particular culture liquid which he used. Even if the production of a toxin by a fungus cannot be established on various culture media, it may still be able to do so on certain plant refuse under natural conditions.

Pythium injury on the roots of wheat manifests itself by a characteristic browning of affected root tips and fine laterals which, when examined microscopically, are found to contain oospores and mycelium usually. It has been observed that plants growing in soil artificially inoculated with a *Pythium* culture on oat-barley medium frequently possess brown root tips in which no trace of a parasite can be found. Very occasionally such roots are found on field-infected material. It seems likely in the light of present findings that this condition may have been caused by toxins produced by the parasite growing on nearby substratum or nearby root, and not directly by penetration of the parasite into the tissues themselves. The work done by Doran (*2*) on brown root rot of tobacco as affected by timothy infusion is of interest in this connection. This author states that his results "lend support to the hypothesis that brown root rot of tobacco is the expression of the injurious effect on tobacco roots of one or more toxic substances which are formed from, and at certain stages in, the decomposition of vegetable organic matter, more especially the residues of certain decomposing crops such as timothy".

In the artificial inoculation of soil, care should be taken to use a medium for the culture of the parasite on which no toxin develops, providing such a medium can be found, in order to determine more definitely the direct parasitic propensities of the organisms themselves. To say that the sterile medium itself when incorporated in the soil produces no ill effects on the plants, does not preclude the difficulty or give a proper control.

Every instance of definite retardation of germination in the experiments described herein, was also associated with conspicuous discoloration of the grain. It is possible that instances of slight toxicity without concomitant discoloration may have been overlooked or confused with effects due to bacterial contamination of the liquids, but as each experiment was conducted in duplicate and in nearly every instance repeated at various times, such does not seem likely. It is suggestive that the brown to black lesions produced by foot- and root-rotting parasites of wheat owe their colour to the same toxins which the fungi are capable of forming on certain culture media.

Preliminary attempts have been made to determine the nature of the toxin. The evidence indicates that it is a decomposition product of the nitrogenous compounds of the substratum, probably an amine. This is in accord with the view of Shaffnit and Lüdtke (*6*).

The question under discussion concerns more than the host-parasite relationship merely: problems of biological antagonism and synergism of soil-inhabiting organisms are involved.

Summary

It has been shown that *P. arrhenomanes* var. *canadensis* and other species of *Pythium* associated with browning root rot of wheat, when grown on specific media, are capable of producing toxins which inhibit the germination of wheat and other cereals and cause a pronounced blackening of the grain. The toxin is thermostable.

It is removed almost completely by the soil in pot culture, but is still effective after passage through a 10-cm. soil column. It is apparently directly poisonous to cells. No sign of dissolution of cell walls is apparent. It does not inhibit the growth of the fungus itself on agar. It readily causes wilting of tomato plants.

Ophiobolus graminis and, to a less extent, *Helminthosporium sativum* and *Fusarium culmorum* also produce substances toxic to wheat depending on the nature of the substrata.

It is pointed out that care should be taken to select culture media on which toxins are not produced by organisms, the relative pathogenicity of which is to be determined in artificially inoculated soil.

The production of toxins by saprophytic as well as parasitic forms gives some idea of the synergistic as well as antagonistic relations of the numerous fungi found associated with various root-rot complexes.

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SPECIES OF *FUSARIUM* ISOLATED FROM FIELD CROPS IN MANITOBA[1]

W. L. Gordon[2]

During 1932, approximately 800 isolations of *Fusarium* spp. were made by Dr. J. E. Machacek, Dominion Rust Research Laboratory, Winnipeg, from diseased roots and bases of wheat, oats, barley and rye collected in Manitoba. A taxonomic study of these isolates has been carried out to determine the identity of the species of *Fusarium* associated with root rots and foot rots of cereals in Manitoba. In this study, the system of classification and nomenclature of the genus *Fusarium* presented by Wollenweber (*1*) in 1931 has been followed.

The isolates consisted of 20 species, varieties and forms of *Fusarium* and represent 7 sections of the genus. In Table 1 is shown the frequency of their occurrence on diseased roots and bases of wheat, oats, barley and rye collected during 1932 in Manitoba. *F. herbarum* v. *avenaceum*, *F. equiseti f. 1*, *F. oxysporum* v. *aurantiacum* and *F. culmorum* were most frequently isolated, accounting for approximately 85% of the total number of isolations. *F. herbarum* v. *avenaceum* was the predominant isolate from wheat, both common and durum, as well as from barley and rye. The isolations made from oats yielded *F. culmorum* more frequently than any of the other species.

It would appear from the results of this study that comparatively few species of *Fusarium* were commonly associated with root rots and foot rots of cereals in Manitoba during 1932.

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[1] *Contribution from the Division of Botany, Experimental Farms Branch, Dominion Department of Agriculture, Ottawa, Canada.*

[2] *Plant Pathologist, Dominion Rust Research Laboratory, Winnipeg, Man., Canada.*

The writer wishes to acknowledge his indebtedness to Dr. C. D. Sherbakoff, Department of Plant Pathology, University of Tennessee, for valuable assistance given in the identification of many of the species of Fusarium recorded in this paper.

TABLE 1.—*The frequency of occurrence of the various species, varieties and forms of Fusarium isolated from wheat, oats, barley and rye in Manitoba.*

Fusarium species	Wheat		Oats	Barley	Rye	Total number of isolations
	Common	Durum				
Discolor						
F. culmorum (W. G. Smith) Sacc.	59	21	33	6	....	119
F. reticulatum Montagne	6	4	....	1	....	11
Elegans						
F. bulbigenum Cke & Mass.		1	1			2
F. bulbigenum Cke & Mass. *v. niveum* (E. F. Smith) Wr.	1			1		2
F. bulbigenum Cke & Mass. *f. l.* Wr.	2		1			3
F. oxysporum Schlecht.	34	9	9	7	2	61
F. oxysporum Schlecht. *v. aurantiacum* (Lk.) Wr.	64	17	14	23	1	119
Gibbosum						
F. equiseti (Cda) Sacc. *f. l.* Wr.	109	37	21	18	1	186
F. equiseti (Cda) Sacc. *v. bullatum* (Sherb.) Wr.	1					1
F. scirpi Lamb. & Fautr.		1		2		3
F. scirpi Lamb. & Fautr. *v. acuminatum* (E. & E.) Wr.	2				1	3
F. scirpi Lamb. & Fautr. *v. filiferum* (Preuss.) Wr.	1					1
Liseola						
F. moniliforme Sheldon	1					1
Martiella						
F. solani (Mart.) App. & Wr.	4	4		1		9
F. solani (Mart.) *v. martii* (App. & Wr.) Wr.	1					1
Roseum						
F. herbarum (Cda) Fr.		1				1
F. herbarum (Cda) Fr. *v. avenaceum* (Fr.) Wr.	155	41	13	28	8	245
F. arthrosporioides Sherb.			1			1
Sporotrichiella						
F. poae (Peck) Wr.	2		2	2		6
F. sporotrichioides Sherb.			1			1
Total number of isolations from each host	442	136	96	89	13	776

SEEDLING DAMAGE OF FLAX CAUSED BY *RHIZOCTONIA SOLANI* AND *PYTHIUM DEBARYANUM*[1]

T. C. VANTERPOOL[2]

In 1930 there was severe damage to flax seedlings in many parts of Saskatchewan. Plants in small areas, or isolated individuals, turned yellow, wilted and died. An examination of affected plants revealed a dry, brown, diseased zone 1 to 4 cm. in extent at the ground level, with occasional brown lesions on the lateral roots. Isolations made at the time of first appearance of the disease yielded mainly pure cultures of *Rhizoctonia Solani*, with an occasional culture of *Fusarium* or *Pythium*. Isolations made later in the season usually yielded *Fusarium* only. Isolates belonging to all three genera proved strongly pathogenic to flax in pot-culture studies in the greenhouse. Each year since 1930, including 1933, there has been a definite trace—always below 1%—of seedling damage or damping-off of flax in all flax fields examined around Saskatoon, and on each occasion pathogenic strains of *R. solani* have been isolated in greatest abundance. The disease is similar to that reported by Brentzel (*1*) in 1923, and described as 'sore shin' by Mackie (*2*).

EXPERIMENTS ON THE PARASITISM OF *R. SOLANI*

Tests on the parasitism of the first strain of *R. Solani* isolated were conducted on flax, sweet clover, wheat, oats, and crested wheat grass, growing in six-inch pots containing sterile soil inoculated with 10 grams of a crushed oat hull culture of the fungus. The germination of the flax was reduced 75 to 100% (Figure 1). Many of the plants which did emerge were subsequently killed. Sweet clover was also susceptible to attack during germination and early growth, but this particular strain of the fungus was only weakly parasitic on wheat, oats and crested wheat grass. In the case of wheat the coleoptile would usually be quite brown and permeated with hyphae of the fungus, but infection of the subcrown internode and other tissues beneath did not occur.

EXPERIMENTS ON THE PARASITISM OF *P. DEBARYANUM*

A strain of *P. debaryanum* isolated in 1930 was tested for its pathogenicity. It prevented the germination of flax completely. After three weeks the soil in each inoculated pot was thoroughly mixed; that in each control pot was also mixed after removal of the flax plants. A second sowing of flax was then made. The results, as seen in Figure 2, show that the fungus has lost little of its virulence. It was not found possible, under the conditions, to determine accurately the relative resistance of Crown, Bison, Buda and Premost varieties.

The following experiment was undertaken in order to ascertain the effect of *P. debaryanum* on growing flax seedlings. These were grown in sterile soil in 2.5-inch pots until about 2 to 3 inches high. Seedlings plus soil were carefully removed by inverting the pot and tapping gently on a wooden bench, and then placed in 6-inch pots containing sterilized soil in the case of controls, and inoculated sterile soil in the remainder. Figure 3, left, shows a representative control pot, and right, an inoculated pot, about two weeks later. Post-emergence damage as well as the better known "damping-off" effect may occur. This strain of *P. debaryanum* was also quite pathogenic to sweet clover during germination and early growth; it occasionally showed weak parasitic ability on wheat, oats and crested wheat grass.

Under similar conditions strong *Pythium* parasites of cereals, *viz.*, *P. arrhenomanes* var. *canadensis* and other species belonging to the *Nematosporangium* group, were found to cause negligible damage to flax and sweet clover.

[1] *Contribution from the Laboratory of Plant Pathology, University of Saskatchewan, with financial assistance from the Saskatchewan Agricultural Research Foundation.*

[2] *Professor of Plant Pathology, University of Saskatchewan, Saskatoon, Sask., Canada.*

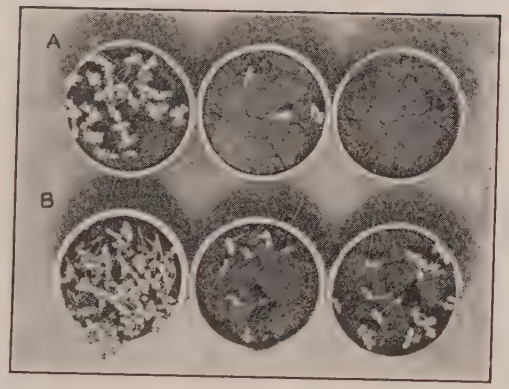

FIGURE 1. *Parasitism of R. Solani on flax, Crown variety. A, sterilized soil; B, unsterilized. In each row the pot on the left was uninoculated, while the centre pots and those on the right were inoculated.*

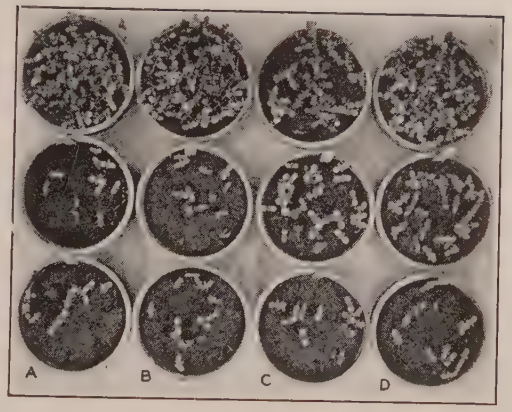

FIGURE 2. *Parasitism of P. debaryanum on flax varieties, A, Crown, B, Bison, C, Buda and D, Premost, showing the results of a second sowing, after the first had failed to germinate in the inoculated pots. Top row, uninoculated; centre and bottom rows, inoculated.*

FIGURE 3. *Post-emergence damage of flax caused by P. debaryanum. About 2 weeks after seedlings in sterilized soil were transferred to larger pots containing sterilized soil, pot on left, and inoculated soil, pot on right.*

Considered practically, the foregoing findings indicate that from the plant disease standpoint a rotation including both monocotyledonous and dicotyledonous plants would be preferable to one of monocotyledonous or dicotyledonous plants alone.

Summary

Field and laboratory studies have shown that early seedling damage or damping-off of flax in Saskatchewan during the last four years has been caused almost entirely by *R. Solani*. *P. debaryanum* may also play a contributory rôle in the moister local tions. Early traces of seedling damage caused by *Fusarium* spp. were found, but typical *Fusarium* wilt did not become of any consequence until later in the growth of the plants. Evidence indicates that some measure of control may be obtained by a rotation of dicotyledonous and monocotyledonous crops.

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